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February 1998

DOE HANDBOOK

RADIOLOGICAL SAFETY TRAINING FOR URANIUM FACILITIES

U.S. Department of Energy
Washington, D.C. 20585

FSC 6910

Order No. DE98001289

Foreword

This Handbook describes a recommended implementation process for additional training as outlined in the *DOE Radiological Control Manual (RCM)*. Its purpose is to assist those individuals, Department of Energy (DOE) employees, Managing and Operating (M&O) contractors, and Managing and Integrating (M&I) contractors identified as having responsibility for implementing the training recommended by the *RCM*. This training may also be given to workers in uranium facilities to assist in meeting their job-specific training requirements of 10 CFR 835. In particular, this material may be useful for developing and providing the facility specific portion of the General Employee Radiological Training, Radiological Worker Training, and Radiological Control Technician Training.

The Handbook contains recommended training materials consistent with DOE standardized core radiological training material. These training materials consist of the following documents:

Program Management Guide - This document contains detailed information on how to use the Handbook material.

Instructor's Guide - This document contains a lesson plan for instructor use, including notation of key points for inclusion of facility-specific information.

Student's Guide - This document contains student handout material and also should be augmented by facility-specific information.

Overhead Transparencies - This document contains overhead transparencies that may be used to augment classroom presentation.

The Handbook was produced in WordPerfect 6.1 and has been formatted for printing on an HP III (or higher) LaserJet printer. The Overhead Transparencies were produced in Microsoft PowerPoint 4.0. Copies of this Handbook (PDF format) can be obtained from the DOE Technical Standards Program Internet site (http://apollo.osti.gov/html/techstds/techstds.html). In addition, electronic files of the training materials in DOE-HDBK-1113-98 can be downloaded from the DOE Radiation Safety Training Internet site (http://tis-nt.eh.doe.gov/wpphm/rst/rst.html) and manipulated using the software noted above (current revision or higher).

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DOE-HDBK-1113-98

(Part 1 of 4)

Radiological Safety Training for Uranium Facilities

Program Management Guide

Coordinated and Conducted
for
Office of Environment, Safety & Health
U.S. Department of Energy

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Course Developers

Melvin Boyd	FERMCO
Gerald Eaton	Westinghouse Hanford Company
Mike Glassic	Laborers AGC
Don Goble	Lockheed Martin Energy Systems
Alan Jeffries	Lockheed Martin Energy Systems
Bruce Nakasone	Rust Geotech
Ed Schultz	Sandia National Laboratory
Paula Trinoskey	Lawrence Livermore National Laboratory
William Ulicny	ATL International, Inc.
Jeff Warga	Information Technologies

Course Reviewers

Peter O'Connell	U.S. Department of Energy
Randy Sullivan	ATL International, Inc.
Technical Standards Managers	U.S. Department of Energy

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Introduction

Purpose and Scope

This program management guide provides guidance for proper implementation of training as outlined in the *DOE Radiological Control Manual (RCM)*. The guide is meant to assist those individuals, Department of Energy (DOE) employees, Managing and Operating (M&O) contractors, and Managing and Integrating (M&I) contractors identified as having responsibility for implementing the training recommended by the *RCM*. Facilities should determine the applicability of this material to support existing programs meant to comply with the training required by 10 CFR 835. Facilities are encouraged to revise these materials as appropriate.

Management Guide Content

The management guide is divided into the following sections:

- Introduction.
- Instructional Materials Development.
- Training Program Standards and Policies.
- Course-Specific Information.

Training Goal

The goal of this training program is to provide a baseline knowledge for those individuals completing the training. Completion of the training provides personnel with the information necessary to perform their assigned duties at a predetermined level of expertise.

Organizational Relationships and Reporting Structure

The DOE Office of Worker Protection Programs and Hazards Management (EH-52) is responsible for approving and maintaining the training materials.

The establishment of a comprehensive and effective contractor site radiological safety training program is the responsibility of line management and their subordinates. The training function can be performed by a separate training organization, but the responsibility for quality and effectiveness rests with the line management.

Instructional Materials Development Next

Instructional Materials Development

Target Audience

Course instructional materials were developed for specific employees who are responsible for knowing or using the knowledge or skills for each course. With this in mind, the participant should never ask the question, "Why do I need to learn this?" However, this question is often asked when the participant cannot apply the content of the program. It is the responsibility of management to select and send workers to training who need the content of the program. When workers can benefit from the course, they can be motivated to learn the content and apply it on their jobs. Care should be taken to read the course descriptions along with the information about who should attend. Participants and DOE facilities alike will not benefit from workers attending training programs unsuitable for their needs.

Prerequisites

A background and foundation of knowledge facilitates the trainee in learning new knowledge or skills. It is much easier to learn new material if it can be connected or associated to what was previously learned or experienced. Curriculum developers who have been involved in preparing instructional materials for the additional standardized training know this and have established what is referred to as "prerequisites" for each course.

Certain competencies or experiences of participants were also identified as necessary prior to participants attending a course. Without these competencies or experiences, participants would be at a great disadvantage and could be easily discouraged and possibly fail the course. It is not fair to the other participants, the unprepared participant, and the instructor to have this misunderstanding.

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Instructional Materials Development (continued)

Training Materials

Training materials for the training program consist of a program management guide, an instructor's guide, a student's guide, and overhead transparencies. This material is designed to be supplemented with updated or facility-specific information.

Supplemental material and training aids may be developed to address facility-specific radiological concerns and to suit individual training styles. References are cited in each lesson plan and may be used as a resource in preparing facility-specific information and training aids.

Each site is responsible for establishing a method to differentiate the facility-specific information from the standardized lesson plan material. When additional or facility-specific information is added to the text of the lesson plan material, a method should be used to differentiate site information from standardized material.

Training Delivery

Sites are encouraged to expand and enhance the training materials through advanced training technologies. Computer-based training and multimedia are samples of such technologies.

Exemptions

Qualified personnel can be exempted from training if they have satisfactorily completed training programs (i.e., facility, college or university, military, or vendor programs) comparable in instructional objectives, content, and performance criteria. Documentation of the applicable and exempted portions of training should be maintained.

Training Program Standards and Policies Next

Training Program Standards and Policies

Qualification of Instructors

The technical instructor plays a key role in the safe and efficient operation of DOE facilities. Workers must be well qualified and have a thorough understanding of the facility's operation, such as processing, handling, and storage of materials, and maintenance of equipment. Workers must know how to correctly perform their duties and why they are doing them. They must know how their actions influence other worker's responsibilities. Because workers' actions are so critical to their own safety and the safety of others, their trainers must be of the highest caliber. The technical instructor must understand thoroughly all aspects of the subjects being taught and the relationship of the subject content to the total facility. Additionally, the instructor must have the skills and knowledge to employ the instructional methods and techniques that will enhance learning and successful job performance. While the required technical and instructional qualifications are listed separately, it is the combination of these two factors that produces a qualified technical instructor.

The qualifications are based on the best industry practices that employ performance-based instruction and quality assurances. These qualifications are not intended to be restrictive, but to help ensure that workers receive the highest-quality training possible. This is only possible when technical instructors possess the technical competence and instructional skills to perform assigned instructional duties in a manner that promotes safe and reliable DOE facility operations.

Technical Qualifications

Instructors must possess technical competence (theoretical and practical knowledge along with work experience) in the subject areas in which they conduct training. The foundation for determining the instructor's technical qualifications is based on two factors:

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Training Program Standards and Policies (continued)

Technical Qualifications (continued)

- N The trainees being instructed.
- N The subject being presented.

The following is an example of a target audience, the subject being taught, and instructor technical qualifications.

TARGET AUDIENCE	SUBJECT BEING TAUGHT	INSTRUCTOR QUALIFICATIONS
Uranium facilities personnel, visitors, DOE employees	Uranium hazards and safety training	Demonstrated knowledge and skills in radiation protection, above the level to be achieved by the trainees, as evidenced by previous training/education and through job performance.

Methods for verifying the appropriate level of technical competence may include the review of prior training and education, observation and evaluation of recent related job performance, and oral or written examination. Other factors that may be appropriate for consideration include DOE, NRC, or other government license or certification; vendor or facility certification; and most importantly, job experience. To maintain technical competence, a technical instructor should continue to perform satisfactorily on the job and participate in continuing technical training.

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Training Program Standards and Policies (continued)

Instructional Capability and Qualifications

Qualifications of instructional capability should be based on demonstrated performance of the instructional tasks for the specific course requirements and the instructor's position. Successful completion of instructor training and education programs, as well as an evaluation of on-the-job performance, is necessary for verification of instructional capability. Instructional capability qualification should be granted at the successful completion of an approved professional development program for training instructors. The program should contain theory and practice of instructional skills and techniques, adult learning, planning, conducting, and evaluating classroom, simulator, laboratory, and on-the-job training activities as applicable to the facility or position.

Illustrated talks, demonstrations, discussions, role playing, case studies, coaching, and individual projects and presentations should be used as the principal instructional methods for presenting the instructional training program. Each instructional method should incorporate the applicable performance-based principles and practices. Every effort should be made to apply the content to actual on-the-job experience or to simulate the content in the classroom/laboratory. The appropriate methodology required to present the instructional content will indicate a required level of instructional qualification and skill.

Current instructors' training, education, and job performance should be reviewed to determine their training needs for particular courses. Based on this review, management may provide exemptions based on demonstrated proficiency in performing technical instructor's tasks.

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Training Program Standards and Policies (continued)

Instructional Capability and Qualifications (continued)

Through training or experience, technical instructors should be able to:*

- Review instructional materials and modify to fully meet the needs of the training group.
- Arrange the training facility (classroom/laboratory or other instructional setting) to meet the requirements for the training sessions.
- Effectively communicate, verbally and non-verbally, lessons to enhance learning.
- Invoke student interaction through questions and student activity.
- Respond to students' questions.
- Provide positive feedback to students.
- Use appropriate instructional materials and visual aids to meet the lesson objectives.
- Administer performance and written tests.
- Ensure evaluation materials and class rosters are maintained and forwarded to the appropriate administrative personnel.
- Evaluate training program effectiveness.
- Modify training materials based on evaluation of training program.

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*Stein, F., *Instructor Competencies: the Standards*. International Board of Standards for Training, Performance and Instruction, 1992.

Training Program Standards and Policies (continued)

Selection of Instructors

Selection of instructors should be based on the technical and instructional qualifications specified in the Course-Specific Information section of this guide. In addition to technical and instructional qualifications, oral and written communication skills, and interpersonal skills, should be included in the process of selecting and approving instructors.

Since selection of instructors is an important task, those who share in the responsibility for ensuring program effectiveness should:

- Interview possible instructors to ensure they understand the importance of the roles and responsibilities of technical instructors and are willing to accept and fulfill their responsibilities in a professional manner.

- Maintain records of previous training, education, and work experience.

Procedures for program evaluation will include documentation of providing qualified instructors for generic and facility-specific training programs.

Test Administration

A test bank of questions for each course that has an exam should be developed and content validated. As the test banks are used, statistical validation of the test bank should be performed to fully refine the questions and make the tests as effective as possible. The questions contained in the test bank are linked directly to the objectives for each course. In this way, trainee weaknesses can be readily identified and remedial procedures can be put into place. The test outcomes can also be used to document competence and the acquisition of knowledge.

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Training Program Standards and Policies (continued)

Test Administration (continued)

The test banks should also be used by the instructors to identify possible weaknesses in the instruction. If numerous trainees fail to correctly answer a valid set of questions for an objective, the instruction for that objective needs to be reviewed for deficiencies.

Written examinations may be used to demonstrate satisfactory completion of theoretical classroom instruction. The following are some recommended minimal requirements for the test banks and tests:

- Tests are randomly generated from the test bank.
- Test items represent all objectives in the course.
- All test bank items are content validated by a subject matter expert.
- Test banks are secured and are not released either before or after the test is administered.
- Trainees should receive feedback on their test performance.
- Test banks should undergo statistical analyses.
- For the first administrations of tests, a minimum of 80% should be required for a passing score. As statistical analyses of test results are performed, a more accurate percentage for a passing score should be identified.

Test administration is critical in accurately assessing the trainee's acquisition of knowledge being tested. Generally the following rules should be followed:

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Training Program Standards and Policies (continued)

Test Administration (continued)

- Tests should be announced at the beginning of the training sessions.
- Instructors should continuously monitor trainees during examinations.
- All tests and answers should be collected at the conclusion of each test.
- No notes can be made by trainees concerning the test items.
- No talking (aside from questions) should be allowed.
- Answers to questions during a test should be provided, but answers to test items should not be alluded to or otherwise provided.
- Where possible, multiple versions of each test should be produced from the test bank for each test administration.
- After test completion, trainees may turn in their materials and leave the room while other trainees complete their tests.
- Trainee scores on the tests should be held as confidential.

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Training Program Standards and Policies (continued)

Program Records and Administration	Training records and documentation shall meet the requirements of 10 CFR 835.704.
Training Program Development/Change Requests	All requests for program changes and revisions should be sent to DOE EH-52 using the "Request for Changes to Standardized Core Training Materials" form provided with each program management guide.
Audit (internal and external)	Internal verification of training effectiveness should be accomplished through senior instructor or supervisor observation of practical applications and discussions of course material. All results should be documented and maintained by the organization responsible for Radiological Control training. The additional standardized training program materials and processes should be evaluated on a periodic basis by DOE-HQ. The evaluation should include a comparison of program elements with applicable industry standards and requirements.
Evaluating Training Program Effectiveness	Verification of the effectiveness of Radiological Control training should be accomplished per DOE/EH-0258T-1, "General Employee Radiological Training and Radiological Worker Training, Program Management Guide." In addition, DOE/EH has issued guidelines for evaluating the effectiveness of radiological training through the DOE Operations Offices and DOE Field Offices. For additional guidance, refer to DOE STD 1070-94, "Guide for Evaluation of Nuclear Facility Training Programs."

Course-Specific Information Next

Course-Specific Information

Purpose	This section of the program management guide is to assist those individuals assigned responsibility for implementing the *Radiological Safety Training for Uranium Facilities.*
Course Goal	Upon completion of this training, the student will have a basic understanding of the characteristics of uranium and the precautions needed for working in an uranium facility, which typically would include uranium fuel cycle facilities or areas contaminated with or storing uranium, or sites involved in cleanup programs such as UMTRA or FUSRAP.
Target Audience	Individuals who have been assigned duties in uranium facilities. These individuals, depending on their job responsibilities, typically would include Radiological Workers. Depending on the facility, portions of the material may be applicable to General Employees and/or Radiological Control Technicians.
Course Description	This course illustrates and reinforces the skills and knowledge needed to provide personnel with an understanding of the characteristics of uranium and the precautions needed for working in a DOE uranium facility. This course is developed in accordance with Article 662 of the RCM. The course material may be useful in developing and providing the facility specific portion of existing standardized core training, especially Radiological Worker Training.
Prerequisites	This training material is designed to augment the DOE Radiological Worker core training. This course includes Radiological Worker training material but is not intended to replace Radiological Worker training. It is recommended that students complete Radiological Worker II training prior to receiving this course, if their job responsibilities require such training. Otherwise, Radiological Worker I training is recommended as a prerequisite.
Length	4 - 8 hours (depending on facility-specific information).

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Course-Specific Information (continued)

Test Bank	On a site-by-site basis.
Retraining	Retraining is not required for this course unless it is used to meet 10 CFR 835 training requirements. In that case, retraining every two years is required. Since some of the content is determined on a facility-specific basis, retraining should also be provided as facility-specific information changes.
Instructor Qualifications	Instructors of this course have a major role in making it successful and meeting the specified objectives. Instructors must have related experience and be technically competent. In this course it is imperative that the instructor have the background and experience of working in a uranium facility. Instructors must be able to relate their own work experience to the workers in an uranium facility. Instructors must be able to answer specific questions and use a variety of instructional material to meet the objectives. Education: Minimum of B.S. degree in Health Physics or related discipline is <u>preferred</u>. Certification: Certification by American Board of Health Physics (ABHP) or National Registry of Radiation Protection Technologists (NRRPT) is <u>preferred</u>. Experience: At least five years of applied radiological protection experience in an operating radiological facility is preferred. Experience in radiological protection at the applicable uranium facility, such as completion of all qualification requirements for the senior-level radiation protection technician position at the trainees' facility, or a similar facility, is preferred. The areas of experience should include:

Continued on Next Page

Course-Specific Information (continued)

Instructor Qualification (continued)

- Radiological controls associated with uranium.
- Conducting surveys and monitoring at uranium facilities.
- Intimate knowledge of Federal regulations and guidance.
- Knowledge of best nuclear industry practices pertaining to radiological protection in uranium facilities.

Through training or experience, technical instructors should be able to effectively communicate, verbally and non-verbally, lessons to enhance learning.

Materials Checklist

The following checklist should be used to ensure all training materials are available. All materials are provided in WordPerfect 6.1® format except for the overhead transparencies, which are provided in Microsoft PowerPoint 4.0 format.

- Program Management Guide.
- Instructor's Guide.
- Student's Guide.
- Overhead Transparencies.

The following checklist should be used before training is provided to ensure equipment is available and working.

- Overhead projector.
- Screen.
- Flip chart.
- Markers.

Bibliography Next

Bibliography: **<u>DOE standards, handbooks, and technical standards lists (TSLs)</u>. The following DOE standards, handbooks, and TSLs form a part of this document to the extent specified herein.**

U.S. Department of Energy, *Guidelines for Evaluation of Nuclear Facility Training Programs*, DOE-STD-1070-94, Washington, D.C. (1994).

U.S. Department of Energy, *Guide to Good Practices for Training and Qualification of Instructors*, DOE-NE-STD-1001-91, Washington, D.C. (1991).

U.S. Department of Energy, *Personnel Selection, Qualification, Training and Staffing Requirements at DOE Reactors and Non-Reactor Nuclear Facilities*, DOE Order 5480.20A.

U.S. Department of Energy, *Radiological Control Manual*, DOE/EH-0256T, Washington, D.C., 1994.

U.S. Department of Energy, *Radiation Protection of the Public and the Environment*, DOE Order 5400.5.

U.S. Department of Energy, *Radioactive Waste Management*, DOE Order 5820.2a.

U.S. Department of Energy, Rich, B. L. et. al, *Health Physics Manual of Good Practices for Uranium Facilities*, EGG-2530, UC-41, 1988.

Title 10, Code of Federal Regulations, Part 835, *Occupational Radiation Protection*.

Los Alamos National Laboratory, *Nuclear Criticality Safety Guide*, LA-12808, 1996.

REQUEST FOR CHANGES TO TRAINING MATERIALS

Send forms to: U.S. Department of Energy
Office of Worker Health and Safety (EH)
Germantown, MD 20874 or fax to: (301) 903-7773
Attn: Peter O'Connell

Date of Request: ___________ Program: _________ GERT _________ RW _________ RCT _________ Other	Lesson No. ________ Page No. ________ Article No. ________ _________ PMG _________ IG _________ SG _________ OT	________________________________ Facility Requesting Change ________________________________ Contact Person ________________________________ Telephone Number - Fax Number

Description of change request:

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Suggested alternative:

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For Official Use Only:

G Accepted
G Accepted as modified, see attachment
G Not accepted, see attachment

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Signature Date

10/97

(Part 2 of 4)

Radiological Safety Training for Uranium Facilities

Instructor's Guide

Coordinated and Conducted

for

Office of Environment, Safety & Health

U.S. Department of Energy

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Course Developers

Melvin Boyd	FERMCO
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Randy Sullivan	ATL International, Inc.
Technical Standards Managers	U.S. Department of Energy

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COURSE MATERIALS

Course Goal:	Upon completion of this training, the student will have a basic understanding of the characteristics of uranium and the precautions needed for working in an uranium facility, which typically would include uranium fuel facilities or areas contaminated with or storing uranium, or sites involved in cleanup programs such as UMTRA or FUSRAP.
Target Audience:	Individuals who have been assigned duties in uranium facilities. These individuals, depending on their job responsibilities, typically would include Radiological Workers. Depending on the facility, portions of the material may be applicable to General Employees and/or Radiological Control Technicians.
Description:	This course illustrates and reinforces the skills and knowledge needed to provide personnel with an understanding of the characteristics of uranium and the precautions needed for working in a DOE uranium facility. This course is developed in accordance with Article 662 of the RCM. The course material may be useful in developing and providing the facility specific portion of existing standardized core training, especially Radiological Worker Training.
Prerequisites:	This training material is designed to augment the DOE Radiological Worker core training. This course includes Radiological Worker training material but is not intended to replace Radiological Worker training. It is recommended that students complete Radiological Worker II training prior to receiving this course, if their job responsibilities require such training. Otherwise, Radiological Worker I training is recommended as a prerequisite.
Length:	4-8 hours (depending on facility-specific information).

Terminal Objective and Enabling Objectives Next

Terminal Objective: At the end of this training, the student will have a basic understanding of the characteristics of uranium and the precautions needed for working in an uranium facility, which typically would include uranium fuel facilities or areas contaminated with or storing uranium, or sites involved in cleanup programs such as UMTRA or FUSRAP.

Enabling Objectives:

EO1 Describe the physical, radioactive, toxicological, and chemical properties and biological effects of uranium.
EO2 Identify the sources and uses of uranium.
EO3 Identify the various processes involved in the nuclear fuel cycle.
EO4 Identify the radiological concerns of external exposure to uranium.
EO5 Describe the measures taken to control external exposure to uranium.
EO6 Identify the modes of entry into the body for uranium.
EO7 Describe the measures taken to control intakes of uranium, including special radiological surveys and techniques, instruments, and release of materials.
EO8 Describe the criticality safety control measures for uranium, including inventory control measures.
EO9 Identify criticality monitoring techniques used with uranium.
EO10 Understand the facility-specific emergency response procedures involving uranium incidents.

Training Aids Next

Training Aids:	Overhead transparencies (may be supplemented or substituted with updated or facility-specific information).
Equipment Needs:	• Overhead projector • Screen • Flip chart or white board • Markers
Student Materials:	Student's Guide Printouts of Overhead Transparencies

Bibliography:

DOE standards, handbooks, and technical standards lists (TSLs). The following DOE standards, handbooks, and TSLs form a part of this document to the extent specified herein.

U.S. Department of Energy, *Guidelines for Evaluation of Nuclear Facility Training Programs*, DOE-STD-1070-94, Washington, D.C. (1994).

U.S. Department of Energy, *Guide to Good Practices for Training and Qualification of Instructors*, DOE-NE-STD-1001-91, Washington, D.C. (1991).

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U.S. Department of Energy, *Radiation Protection of the Public and the Environment*, DOE Order 5400.5.

U.S. Department of Energy, *Radioactive Waste Management*, DOE Order 5820.2a.

Title 10, Code of Federal Regulations, Part 835, *Occupational Radiation Protection*.

Los Alamos National Laboratory, *Nuclear Criticality Safety Guide*, LA-12808.

Lesson Summary Next

LESSON SUMMARY

Introduction:

Welcome students to the course.

Introduce self to the participants and establish rapport.

Define logistics:

- o Safety briefing - exits.
- o Restrooms.
- o Hours.
- o Breaks.
- o Sign-in sheets.
- o Test accountability (if applicable).
- o End-of-course evaluation.

Remind the participants that they need to have completed Radiological Worker training prior to or in conjunction with this course. They should be familiar with terms like rem, contamination, etc.

Terminal Objective:

At the end of this course, the student should demonstrate a basic understanding of the characteristics of uranium and radiological precautions necessary for working at a uranium facility.

State Enabling Objectives.

COURSE CONTENT

Briefly review the content of the course, noting the logical sequence ("flow"). State that as you present the material to be covered, you will relate it to the circumstances that the students can expect to find in the facility workplace and procedures. (You will be inserting facility-specific uranium information.)

Course Content Continued on Next Page

COURSE CONTENT (cont.)

MODULE 101 - Properties of Uranium

MODULE 102 - The Nuclear Fuel Cycle

MODULE 103 - External Dose Control

MODULE 104 - Internal Dose Control

MODULE 105 - Criticality Safety

MODULE 106 - Emergency Response for Uranium Incidents

MODULE 107 - Course Summary

This training should be used to supplement the Radiological Worker training materials for personnel working at or having access to DOE uranium facilities. This training is multi-faceted, and different sections can be applied to various target groups.

Lesson Plan and Instructor's Notes Next

Lesson Plan	Instructor's Notes
I. MODULE 101 - Properties of Uranium	Show OT-1
A. Objective	Show OT-2 Show OT-3
EO1 Describe the physical, radioactive, toxicological, and chemical properties and biological effects of uranium.	
B. Physical Properties	Show OT-4
Uranium can be encountered as a solid, liquid, or gas, depending on its chemical form and surrounding conditions. Each of these physical forms has particular hazards. Sometimes, changing the form of uranium can lead to radioactive decay products accumulating or becoming concentrated in a particular location, such as on the surface of a liquid. The result can be an apparent increase in the radioactivity.	
1. Solid	Provide a facility specific example of uranium in a solid form.
The solid forms of uranium are generally the most stable configurations. The shiny, silvery metal form is rarely seen except in a workshop when it is being machined. After machining, the surface oxidizes, typically within hours, to a hard, black surface.	
After some time, depending on temperature, humidity, and alloy, the surface may change color and begin to flake. Orange or yellow colored surfaces are usually more flaky and soluble. In these forms, contamination can be more easily spread, inhaled, and absorbed into the body.	

Lesson Plan	Instructor's Notes
2. Liquid	Provide a facility specific example of uranium in liquid form.
Uranium melts at 1133°C, so molten uranium is unusual, except in a foundry. It has often been observed that the radioactivity appears to increase when uranium is melted. This is because radioactive decay products, such as radium and thorium, float to the surface. The density of radium is 5 g/cm^3, compared with 19 g/cm^3 for uranium; therefore, radium floats in molten uranium.	
Uranium in contact or solution with water is common. The primary hazards associated with a uranium solution are criticality (for enriched uranium) and spills. Water decreases the quantity of enriched uranium required for criticality. This topic will be discussed in Module 105 - Criticality Safety.	
3. Airborne Powder	Provide a facility specific example of uranium in airborne powder form.
A spill of any radioactive solution is a concern. As the solution evaporates, it leaves behind a radioactive residue, or powder, that can easily become airborne. Airborne uranium may be inhaled and absorbed into the bloodstream through the lungs.	
4. Gas	Provide a facility specific example of uranium in gaseous form.
Another form of uranium that is an inhalation hazard is the volatile UF_6, becoming a gas above 56°C. However, most uranium daughters are not volatile,	

Lesson Plan	**Instructor's Notes**
and so can accumulate in storage cylinders. When the volatile UF_6 is extracted, the nonvolatile daughters remain in the cylinder, resulting in the buildup of residual radioactivity. However, in the case of uranium-232 (^{232}U), uranium-235 (^{235}U), and uranium-238 (^{238}U), each of these uranium isotopes has a radon daughter. Radon is a gas at all but very low temperatures; therefore, if the radon escapes, the subsequent daughters can accumulate in closed or poorly ventilated areas.	
In some situations, pressure from volatilized UF_6 gas can build up in small volumes such as a sealed container or a pipe run between two valves. Line breaks and leaks will cause a release of the UF_6. As the escaping UF_6 gas cools, it becomes particulate, which may have a suffocating effect on any nearby workers.	
Another reason for pressure buildup is alpha particles emitted in radioactive decay eventually becoming inert helium gas. The amount is only significant for high specific activity forms of uranium. For example, a sample of 99% uranium-233 (^{233}U) with 1% ^{232}U creates approximately its own volume of helium gas every year. Sealed containers must include adequate gas space or be fitted with pressure release valves. Once the pressure is relieved, the low-pressure helium gas is harmless.	

Lesson Plan	**Instructor's Notes**
Hydrogen gas is generated from uranium in water, and this may also produce a pressure buildup situation. Because the hydrogen buildup may also be a fire hazard, it is discussed later in this module in the Chemical Properties section.	
C. Radioactive Properties	Show OT-5
Uranium in its pure metal form is a silvery, gray metal and is the heaviest naturally occurring element. There are 18 separate isotopes of uranium. Isotopes are elements that have the same number of protons, but different numbers of neutrons. For example, ^{235}U has 92 protons with 143 neutrons and ^{238}U has 92 protons with 146 neutrons.	
Uranium is radioactive. Partially because of its size, the nucleus of a uranium atom is unstable. It reduces its size either by alpha particle emission or by nuclear fission, in which the uranium nucleus splits, primarily, into two smaller fission products. Both processes release energy, which can be helpful or harmful depending on how they are controlled.	
All isotopes of uranium are fissionable, which means they can be fissioned by fast neutrons. Two isotopes, ^{233}U and ^{235}U, are fissile, which means they can also be fissioned by slow (thermal) neutrons. A fissile material can be involved in a criticality accident, resulting in the release of a lethal amount of radiation. Criticality is discussed in more detail in Module 105 - Criticality Safety.	

Lesson Plan	**Instructor's Notes**
The primary isotopes of uranium are all long-lived alpha emitters. However, several other radionuclides can be radiologically significant at uranium facilities, depending on the history of the uranium materials and the processing. These other radionuclides include the following beta emitters: ^{234}Th, ^{234m}Pa, ^{231}Th, and ^{99}Tc. The degree of enrichment also affects the controls that are required for external radiation exposure because of the increase in the amount of gamma-emitting ^{235}U that is present. The uranium daughter products may also include some low-energy gamma and x-ray radiation. For example, the daughter products of ^{232}U represent a potential gamma-emmission hazard. Although there are several isotopes of uranium, only three exist naturally, and all three are radioactive. See the table below for half-lives and natural percent abundance for important uranium isotopes in the nuclear fuel cycle.	

Lesson Plan | **Instructor's Notes**

ISOTOPE	HALF-LIFE	NAT. ABUND.	IMPORTANCE
^{232}U	70 y	0%	An unwanted byproduct of ^{233}U production in a breeder reactor. Due to its much shorter half-life, ^{232}U contributes most of the radioactivity in samples of ^{233}U.
^{233}U	1.6×10^{5} y	0%	Manufactured by irradiating ^{232}Th with neutrons. It is a criticality hazard because it is fissile.
^{234}U	2.5×10^{5} y	0.0055%	A decay product of ^{238}U. It is concentrated with ^{235}U during enrichment. Highly enriched uranium contains about 1% ^{234}U. Most of the radioactivity of enriched uranium is from the ^{234}U.
^{235}U	7.1×10^{8} y	~0.7%	Fissile with slow neutrons; therefore, it is of primary interest for reactors and weapons. If not handled safely, an accumulation of ^{235}U could become critical.
^{236}U	2.3×10^{7} y	0%	Some ^{235}U is converted to ^{236}U in reactors. It is also present in reprocessed reactor fuel.
^{238}U	4.5×10^{9} y	~99.3%	The most abundant uranium isotope. It is fissionable with fast neutrons; however, it is not fissile (i.e., with thermal neutrons) so it is not a criticality hazard.

As uranium goes through radioactive decay, it produces other radioactive elements known as radioactive decay products (also called progeny or daughter products). These radioactive

Show OT-6

Lesson Plan	**Instructor's Notes**
decay products are also radioactive and have to be taken into account for radiological protection purposes.	
Both alpha and beta particles are emitted as part of decay series. For example, ^{238}U decays by alpha emission to ^{234}Th; ^{234}Th decays by beta emission to ^{234m}Pa; and so on, until stable ^{206}Pb is finally reached.	
1. Decay Series	Show OT-7
Uranium has two naturally occurring decay series: the "actinium" series, which has ^{235}U as its parent; and the "uranium" series, which has ^{238}U as its parent. Many of our everyday encounters with radioactivity come from these decay series; examples are radon gas and radium.	Discuss decay products resulting in radiological concerns at your facility. Refer to the *Health Physics Manual of Good Practices for Uranium Facilities* for specific technical information on different isotopes of uranium.
There are also man-made isotopes of uranium - ^{232}U and ^{233}U. These radionuclides and their decay products must be considered in the implementation of a radiological control program at a facility where these uranium nuclides are present.	
2. Criticality	
Uranium is a fissionable material, which means it can undergo nuclear fission. Nuclear fission is a process in which a very heavy, unstable atom splits in two, or "fissions". When an atom fissions, one large atom primarily becomes two smaller atoms, between one and seven neutrons are given off (which may cause	

Lesson Plan	Instructor's Notes
fission in nearby atoms), and a great deal of energy is given off as radiation and in other forms, such as kinetic energy of the fission fragments. The radiation created could result in the creation of radiological areas, such as High or Very High Radiation Areas. Nuclear criticality associated with uranium will be discussed in greater detail later in the lesson.	
D. Chemical Properties	
Uranium is chemically reactive. It burns in air like magnesium; it is toxic like lead; and it forms a large variety of chemical compounds. All the isotopes of uranium have the same chemical reactivity, and all can be made into the many different physical and chemical forms discussed in this section.	
1. Fire	Show OT-8
Uranium is a metal that will sustain a burning reaction (similar to a magnesium flare). The potential for a fire is greatest when the uranium is in a finely divided form, such as milling chips or filings. In this form, uranium can undergo spontaneous ignition. Uranium metal is often machined to provide a useful end product, and milling chips and filings are unavoidable byproducts.	
Precautions must be taken to prevent chips and filings from igniting. One precaution is submersing the chips and filings in water or a mineral oil. Storage in	

Lesson Plan	Instructor's Notes
water produces hydrogen gas due to a chemical reaction. To prevent the hydrogen gas from reaching an explosive concentration, and to prevent a pressure buildup, containers must be vented. Incidents have occurred where container lids have been blown off by unexpected gas pressure buildup.	
Once uranium starts to burn, it is extremely difficult to extinguish. None of the typical extinguishing methods, such as water, carbon dioxide, or halon, is effective in fighting uranium fires. In fact, halon may be explosive and produce toxic fumes if used directly on the fire.	
Normally, small fires may be put out by using MET-L-X powder, which is a mixture of sodium chloride (table salt) and potassium carbonate (baking powder). When spread over the burning metal in significant quantities, MET-L-X starves the fire of oxygen.	
Larger fires, such as with storage drums, are more difficult to extinguish. Submersion in water will eventually work once the metal cools down. However, continuous water addition is necessary to make up for losses due to boiling and evaporation.	The Chernobyl disaster resulted in a graphite reactor core fire that burned for days.
2. Toxicological/Biological Effects	Show OT-9
The principal entry of uranium into the human system is due to either inhalation or ingestion. Inhalation occurs either from release of volatile uranium	

Lesson Plan	Instructor's Notes

compound or from suspension of volatile uranium-laden aerosols. Ingestion can occur when the uranium is introduced into water for consumption or the food chain by plant uptake. When uranium is either ingested or inhaled, it is removed from the body with a biological half-life varying between 6 and 5000 days, depending on which organ has become contaminated. Uranium tends to concentrate in the kidneys and the bones. Additionally, if inhaled, the lungs are exposed. Internal exposure to uranium is controlled by limiting the ingestion and inhalation of this element. These methods, along with measurement techniques, are discussed in Module 104.

Most heavy metals, such as uranium, are toxic to humans depending on the amount introduced into the body. For short-term (acute) exposures, the toxicological effects are the primary concern, and acute exposures to significant amounts of uranium may result in kidney damage. However, as the enrichment of the uranium in the ^{235}U isotope increases, so too do the effects of radiation exposure in relation to toxicological effects.

Past industrial experience has proven that if there is a long-term exposure of small amounts of uranium (chronic exposure), the radiological effects are the primary biological concern. In fact, for chronic exposures, a development of tolerance against the toxicological effects may occur. The principal

Lesson Plan	**Instructor's Notes**

radiological hazard associated with uranium is due to the relatively high energy alpha particles its radionuclides and daughters emit. A chronic exposure to these radionuclides result in an increased risk of cancer, typically in the bones, kidney, and lungs, since these are the organs where uranium is deposited.

3. Chemical Reactivity

Show OT-10

The chemistry of uranium is complicated. For example, uranium forms several oxides: UO, UO_2, UO_3, and UO_4. In general, a sample of uranium oxide will include a mixture of several of these. For example, U_3O_8 is sometimes written as (UO_2)C2(UO_3).

The lower oxidation states, UO_2 and U_3O_8, tend to be dark brown or black. The higher oxidation states, UO_3 and UO_4, are generally orange or yellow, especially in solution or if water or crystallization are present (e.g., UO_4C2H_2O). Furthermore, the higher oxides usually flake off more easily and are usually more soluble in water. Being flaky, they are more easily inhaled. Being more soluble, they are more easily absorbed into the body.

Show OT-11

Uranyl compounds, such as uranyl nitrate, or $UO_2(NO_3)_2$, are chemical forms of uranium that are often found in solution with water. They are

Lesson Plan	**Instructor's Notes**
generally yellow in color and are used in criticality experiments.	
Uranium reacts readily with air and water. For example, when uranium is machined, small chips catch fire from the heat of the machining process. Shavings placed in water react to produce hydrogen gas. The surfaces quickly oxidize to a hard black coating that is at first protective; however, under adverse conditions, it corrodes and flakes.	Show OT-10 again
Uranium also reacts with hydrogen or tritium gas to form uranium hydride (UH_3). Uranium "beds" are commonly used to store tritium.	
Uranium hexafluoride (UF_6) reacts in moist air to produce hydrogen fluoride (HF) gas, which is corrosive and can damage the lungs if breathed. Inhalation of HF has resulted in fatalities following UF_6 releases.	
The chemical form of uranium is dependent on its intended use and its stage of production. For example, UF_6 is used during the enrichment process, and UO_2 is used as nuclear fuel. When handling uranium compounds, the possibility of chemical reactions must not be overlooked.	

Lesson Plan	Instructor's Notes
II. MODULE 102 - The Nuclear Fuel Cycle	Show OT-12
A. Objectives	
EO2 Identify the sources and uses of uranium.	
EO3 Identify the various processes involved in the nuclear fuel cycle.	
B. Importance of Uranium	Show OT-13
Uranium is a naturally occurring element used primarily for producing energy with nuclear reactors and developing nuclear weapons. It is also used for armor plating (depleted uranium), radiation shielding, and counterweights.	
Historically, uranium was used for hundreds of years to color glass and as a glaze for tile and pottery. Bright orange "Fiesta-ware" dinner plates were prized for their color without any awareness of their radioactivity. These plates are no longer produced, but are now collectors' items among those in the nuclear industry and others. Typically, the dose rate is about 5 mrem/hr (0.05 mSv/hr) on contact with these plates.	
The original discovery of radioactivity involved uranium. In 1896, Henri Becquerel discovered that uranium would cause photographic film to become fogged because of radioactive emissions. Some of these emissions were even more penetrating that the "X rays" that Wilhelm Roentgen had discovered a year earlier.	

Later investigators, such as Marie Curie, isolated other radioactive elements from uranium ores. These elements are produced from the radioactive decay of uranium. The radioactive emission of an alpha particle causes uranium to change into thorium. Thorium goes on to decay to other elements, and so on, until a stable element such as lead is reached.

Radium and radon are the two most well-known radioactive decay products of uranium. Radium was once used for luminous instrument dials and other products. Radon is a heavy radioactive gas that can accumulate in buildings and mines. Typically, these radioactive decay products are more hazardous than the uranium itself.

The importance of uranium increased dramatically with the discovery of nuclear fission in 1938, the production of plutonium in 1940, and the construction of the first reactor in 1942 under the direction of Enrico Fermi. These accomplishments led to the Manhattan Project, in which uranium was enriched at Oak Ridge or converted into plutonium at Hanford. These products were used to assemble the first atomic bombs at Los Alamos in 1945.

After the end of World War II in 1945, the importance of uranium remained high. Production of uranium and plutonium for "atomic" or "nuclear" weapons continued throughout the Cold War. In addition, nuclear reactors were built for the propulsion of naval submarines and ships, and for the commercial production of electricity. Now, most of the world's production of uranium is used for nuclear reactors.

Lesson Plan		Instructor's Notes
C.	Sources of Uranium	Show OT-14
	Uranium is found in the earth's crust and is mined as ore. The average concentration is 2 parts per million (ppm) in the crust and less than 2 parts per billion (ppb) in the oceans. During the 1960's and 1970's, a program titled the Natural Uranium Resource Exploration was funded by the government to identify the locations of desirable uranium ore throughout the United States. It was determined that the most desirable locations of uranium are in the Colorado Plateau, the Wyoming Basin, and the flanks of the Black Hills in South Dakota. In those locations, the uranium concentration is much higher than 2 ppm. Uranium is also found on the African Continent. The ore is removed from either shallow open pits (less than 300-foot, or100 m, depths) or underground mines (greater than 300-foot depths). The typical uranium content of the ore is 0.15 - 0.3 percent and is in the form of U_3O_8, which is called "yellowcake." Uranium is also found in secondary minerals in the following forms: complex oxides, silicates, phosphates, and vanadates.	Show OT-15
D.	Uranium Operations and Processes	Show OT-16
	Uranium processing is dependent upon the desired product, but it generally involves the following cycle: • mining and milling, • conversion, • enrichment, • fabrication,	Discuss the use of uranium at your site as it is described in this section of the lesson plan.

Lesson Plan	Instructor's Notes
• use, • waste disposal/storage, and • decontamination and decommissioning.	
1. Uranium Mining and Milling	Show OT-17
After removal from the mine, the uranium ore is milled to extract the yellowcake. This involves the following process:	
a. The ore is crushed, ground, and mixed with water to prepare for chemical processing.	
b. The crushed ore and water mixture is mixed with chemicals to separate the yellowcake from the ore. This separation process is called "leaching." The resultant products include a slurry of yellowcake ready for additional processing and a mixture of low-grade crushed rock and sand called "mill tailings."	
Only about 3 percent of the actual material removed from the mine ends up as yellowcake, which means that millions of tons of mill tailings are leftover. Yellowcake contains 70-90% by weight of uranium oxides. The leftover mill tailings are a concern because they still contain some of the uranium ore . Additional hazards exist due to the chemicals added.	

Lesson Plan	Instructor's Notes
It is estimated that the uranium milling in the United States left approximately 138 million tons of mill tailings covering about 3,000 acres of land.	
c. The yellowcake slurry is then purified by either ion exchange or solvent extraction.	
d. Following purification, the yellowcake slurry is dried, forming a concentrated yellowcake compound that contains 75 - 98 percent uranium. The yellow color is caused by the addition of leaching chemicals and their eventual removal during the drying step. The final color can range from yellow to orange to black depending on the chemicals used and the drying temperature.	
The final color is a good indicator of solubility, and thus of biological effects if uranium in this form is taken into the body. Less soluble uranium compounds tend both to remain in the body longer and to be darker in color. More soluble uranium compounds are removed from the body more quickly by normal body functions, and tend to be lighter in color.	

Lesson Plan	Instructor's Notes

2. Conversion

Show OT-18

At this stage in the nuclear fuel cycle, the yellowcake is converted into uranium hexafluoride (UF_6) for enrichment. This is accomplished by:

a. Conversion of yellowcake to pure uranium trioxide (UO_3), called "orange oxide" or "orange salt," by solvent extraction and follow-up drying.

b. Conversion of UO_3 to uranium dioxide UO_2.

c. Conversion of UO_2 to uranium tetrafluoride (UF_4) by hydrofluorination (addition of hydrogen fluoride gas). This product is called "green salt."

d. Reacting the UF_4 with fluorine gas (F_2) to form uranium hexafluoride (UF_6), which is a volatile form ready for enrichment. The UF_6 is a solid at room temperature but readily becomes a gas when heated above 56°C.

3. Enrichment

Show OT-19

The enrichment process is necessary to increase the percentage of the ^{235}U isotope in the uranium to make it suitable for reactor fuel. Natural uranium contains 0.7% ^{235}U. Typically, enriched uranium contains 2-4% ^{235}U. Other uses may require much higher

Lesson Plan	Instructor's Notes

concentrations up to, or even greater than, 90% ^{235}U. Depleted uranium, which is left over after the enrichment process, has an abundance of about 0.2% ^{235}U.

The methods used to enrich uranium include:

a. *Gaseous Diffusion*

Gaseous diffusion is based on principles of gas laws. The UF_6 gas is forced through converters by large compressors. The converters contain many tubes made of a special barrier material that is porous. The $^{235}UF_6$ molecules are lighter than the $^{238}UF_6$ molecules and bounce against the porous barrier more frequently. The $^{235}UF_6$ has a greater chance of passing through the barrier, resulting in a slightly richer ^{235}U content. It may take as many as a thousand passes to obtain the desired degree of enrichment.

b. *Laser Processes*

The Atomic Vaporization Laser Isotope Separation (AVLIS) involves vaporization, selective ionization of one isotope, and subsequent electrical separation. Currently, no DOE production plants exist which use this technology.

Lesson Plan	**Instructor's Notes**

c. *Nozzle Separation*

The nozzle separation process is based on the different speeds of ^{235}U and ^{238}U compounds when they are injected through a nozzle into a small chamber.

d. *Centrifugal Separation*

Centrifugal separation is based on heavier compounds migrating to the outside when spun at a high rate of speed.

The uranium left over from the enrichment process is mostly ^{238}U, with a reduced amount of ^{235}U (usually 0.2% by weight). This byproduct is called "depleted uranium" and has additional uses such as radiation shielding, armor plating, and ammunition.

During World War II, uranium work was secret and code names were used for the different forms of uranium. Natural uranium was named "Tuballoy," a name that grew out of a cover story that the Allies were investigating alloys for high-quality tubing. Highly enriched uranium was then named "Oralloy" for "Oak Ridge Alloy," sometimes abbreviated to "Oy." Depleted uranium was once called depletalloy, but more commonly was called "D-38" since it consists mostly of ^{238}U. These historical names are sometimes still used within the DOE complex.

Lesson Plan	**Instructor's Notes**

4. Fabrication

The last step in the nuclear fuel cycle is changing the enriched uranium into an appropriate form for fabrication. The fabrication process differs depending on the application. For fabrication of fuel elements, the process generally includes the following steps.

a. Uranium dioxide (UO_2) is produced by reacting UF_6 with water and then with a hydroxide salt.

b. The resulting precipitate is dried to form "orange oxide," which is reduced with hydrogen to form UO_2 powder.

c. The UO_2 powder is compacted into cylindrical pellets that are loaded into thin-walled tubes made of either stainless steel or an alloy of zirconium called "zircalloy."

d. Helium, an inert gas, is pumped into the tubes, which are then capped. A cluster of these tubes separated by spacers forms a reactor fuel assembly.

Fabrication of other materials, such as weapons parts, may also include materials made with uranium.

Lesson Plan	**Instructor's Notes**
5. Uses	Show OT-20
The primary goal of the uranium fuel cycle process is to yield enriched uranium. This product can be used for: • power reactors, • research reactors, • nuclear weapons, and • naval propulsion reactors.	
There are also a number of uses for uranium metal depleted in the ^{235}U isotope, such as: • radiation shielding, • armor-piercing bullets, • catalysts for chemical reactions, • armor plating, and • counter weights.	Show OT-21
Depleted uranium typically is cast into ingots or billets, and then shipped to production facilities for appropriate reshaping.	
6. Reprocessing	Show OT-22
Reprocessing of spent nuclear fuel is no longer performed in this country. This information is provided for the purpose of describing how the process worked at applicable facilities.	

Lesson Plan	Instructor's Notes
Uranium was used in plutonium production reactors. Uranium fuel and targets were coated with aluminum or zirconium metal and placed in the reactor. As they were irradiated with neutrons, a small fraction of the uranium was converted to plutonium. The irradiated fuel was then removed from the reactor, but the plutonium and uranium had to be separated from the fission products created during irradiation.	
PUREX, a chemical process for **p**lutonium and **ur**anium **ex**traction from irradiated nuclear fuel, was developed to accomplish this separation. This reprocessing was accomplished as follows:	
a. Excess metal was mechanically removed to expose the fuel material.	
b. The fuel was leached with acid to remove it from the cladding.	
c. The uranium and other elements were separated by solvent extraction (chemical separation).	
d. The uranium was converted back to UF_6 for enrichment.	
7. Waste Disposal and Storage	Show OT-23
Due to the remaining radioactive properties, the nuclear fuel cycle byproducts must be controlled	

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and/or disposed. These byproducts can be divided into two categories—low-level waste (LLW) and high-level waste (HLW).

a. *LLW*

The RCM glossary defines low-level waste (LLW) as "Waste that contains radioactivity and is not classified as high-level waste, transuranic waste, spent nuclear fuel, or byproduct material as defined in Section 11e(2) of the Atomic Energy Act, as amended. Test specimens of fissionable material irradiated only for research and development and not for production of power or plutonium may be classified as low-level waste provided the concentration of transuranic activity is less than 100 nCi/g." LLW could be in the form of liquids, solids, or gasses. Liquid waste is usually processed to remove radioactive material and then recycled or disposed.

Solids may be volume-reduced by incineration or compaction. Soluble forms in liquid may be solidified to isolate radioactive contents.

Gases are either changed to a solid form and disposed of as a solid or compressed and stored as gases. These gases may be released

Lesson Plan	Instructor's Notes
after sufficient time has elapsed for decay of the radioactive component of the gas.	
b. *HLW*	
High-level waste (HLW) is defined in DOE Order 5820.2a as "The highly radioactive waste material that results from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid waste derived from the liquid, that contains a combination of transuranic waste and fission products in concentrations requiring permanent isolation.	
HLW comes primarily from the reprocessing of spent fuel. It is typically in liquid form, and it is collected and stored in tanks. The liquid waste is then solidified (stabilized) for disposal. All HLW is ultimately to be disposed of by deep burial.	
8. Decontamination and Decommissioning of Uranium Facilities	Show OT-24
Uranium and its byproducts from the nuclear fuel cycle may present health risks due to radioactivity or chemical properties. Past and present DOE uranium facilities and their surrounding areas may contain contamination from uranium or its byproducts. DOE recognizes that they have a responsibility to restore	

Lesson Plan	Instructor's Notes

these potentially contaminated facilities and surrounding areas to a nonhazardous condition. To accomplish this, several "remediation" programs are in place and others are developing.

Some cleanup programs include:

a. Uranium Mill Tailings Remedial Action (UMTRA) Program

This program is intended to cleanup uranium mill sites and associated "vicinity properties." It covers 24 mill sites and more than 4,800 properties throughout the Nation. The goals of the program are to reduce radon release from mill tailings to acceptable levels by burial, and to restore affected land and facilities/structures to unrestricted use.

b. Formerly Utilized Sites Remedial Action Program (FUSRAP)

This program is intended to clean up uranium-contaminated DOE contractor facilities that processed uranium ores for the Manhattan Project.

Lesson Plan	Instructor's Notes
c. Surplus Facilities Management Program (SFMP) This program covers sites that are being restored for unrestricted use. Each cleanup project presents different types and levels of hazards to workers. Additionally, general safety hazards become a significant factor due to the types of processes and equipment used to remove the uranium-contaminated materials. Usually these projects require some level of structural decontamination and soil remediation.	

Lesson Plan	Instructor's Notes
III. MODULE 103 - External Dose Control	Show OT-25
A. Objectives	Highlight the specific external exposure hazards and controls at your facility.
EO4 Identify the radiological concerns of external exposure to uranium.	
EO5 Describe the measures taken to control external exposure to uranium.	
B. Alpha External Dose	
Because of the relatively short range of alpha particles in dense matter, alpha radiation poses little external dose hazard. The most energetic alphas produced by naturally occurring radionuclides will barely penetrate the dead layer of skin on the human body. Little living tissue will be affected when the alpha source is external to the skin.	
C. Beta External Dose	Show OT-26
Beta doses to the skin, extremities, and the lens of the eye can be limiting in facilities which process unshielded depleted, natural, or low-enrichment uranium. Processes which separate and sometimes concentrate beta-emitting uranium daughters are not uncommon in DOE uranium facilities. Control of exposure is complicated by the fact that considerable contact work takes place in facilities which process uranium metal.	
Several uranium radioactive decay products are beta emitters. Normally, most of these betas are shielded by the surrounding	

Lesson Plan	Instructor's Notes
material or material worn as personal protective clothing (such as Tyvek). A primary radionuclide of concern is protactinium-234 in its metastable state (^{234m}Pa), a daughter of ^{238}U which produces a very high energy beta particle that can travel up to 20 feet in air. Significant beta radiation is also emitted from ^{234}Th (also a daughter of ^{238}U) and ^{231}Th (a daughter of ^{235}U). Typically, these are shielded with ½-inch of plastic.	Discuss all other beta emitters of importance at your facility.
D. Gamma and X-Ray External Dose	Show OT-27
Although beta dose from unshielded uranium presents the most common radiation problem, storage of large quantities of uranium can create low-level gamma radiation fields (less than 5 mrem/hr). Such fields can create external exposure problems, particularly when significant numbers of people are working in adjacent areas.	
In addition to gamma emissions from the uranium decay chains (^{238}U and ^{235}U), recycled fuel materials introduced back into the enrichment process will result in higher gamma radiation fields because of ^{228}Th, a gamma-emitting daughter of ^{232}U with a relatively short half-life (1.9 yr).	
Larger sources of gamma radiation may exist from specific uranium processes, including unflushed UF_6 cylinders. Gamma radiation emitted from residual materials can result in gamma radiation fields of several hundred millirem per hour. This problem can be controlled by flushing empty cylinders to remove residual material.	

Lesson Plan	**Instructor's Notes**
E. Neutron External Dose	
As uranium is processed in the fuel cycle, it is often chemically bonded to fluorine to create compounds such as UF_4 and UF_6. When uranium atoms in these compounds decay, they emit alpha particles that are sometimes captured by the neighboring fluorine atoms. The resulting atom is unstable and may emit a neutron to gain back its stability. The neutrons emitted can result in neutron radiation fields between 0.5 and 4 mrem/h.	Show OT-28
The probability of spontaneous fission is small; therefore exposure is not expected. However, if fission does occur, such as in a reactor or from experiments, the neutron radiation is typically contained. Neutron radiation that is not contained is usually the result of a criticality accident, which generates potentially fatal doses of gamma radiation.	
F. External Dose Measurements	
The radiation from uranium that affects external dose includes beta, gamma, X-ray and neutron irradiation. An effective external exposure control program for uranium requires a variety of radiation detection instruments that are responsive to these forms of radiation. Radiation surveys should be performed on a routine basis and during events, tasks, procedures, or situations that are likely to cause radiological conditions to change. There are two general categories of measurement used for external exposure associateed with uranium, portable survey instruments and personnel dosimeters.	

Lesson Plan	**Instructor's Notes**
Gamma radiation from uranium is normally not the controlling problem. For example, the contact beta radiation field from depleted uranium is approximately 240 millirem per hour, while the contact gamma radiation field is less than 10 millirem per hour. However, significant gamma fields can exist in areas where large quantities of uranium are stored, such as a storage area for uranium contaminated soil. The accuracy and precision of survey instruments used for measurement of beta radiation fields depend on many factors which must be addressed, such as energy response and geometry factors. Accordingly, these surveys are typically conducted by Radiological Control personnel. Neutron fields from enriched uranium fluoride compounds can also add to this area of concern. Depending on the magnitude of neutron fields generated, periodic neutron dose rate measurements are made, typically by Radiological Control personnel.	
Personnel dosimeters produce the data which becomes the formal or "legal" record of personnel exposure, thermoluminescent dosimeters, used in most DOE uranium facilities, provides the most accurate and precise means of measuring doses received by workers.	Discuss the facility specific methods for measuring external exposure and dose.
G. External Dose Reduction and Control Techniques	
1. External Dose Control Program	
The primary purpose of an external dose control program is to control dose to the individual radiation worker to below regulatory limits and administrative	

Lesson Plan	Instructor's Notes
levels and ensuring that doses are As Low As Reasonably Achievable (ALARA). In all cases at DOE facilities, dose received by an individual shall not exceed the limits specified in Title 10 of the Code of Federal Regulations, Part 835 (10 CFR 835).	
The elements of an external dose control program include:	
• detecting and characterizing the beta, gamma, X-ray, and neutron radiation fields; • measuring and/or quantifying these radiation fields; • measuring personnel exposure; and • determining external exposure control practices.	
2. General External Dose Control Practices	Show OT-29
These general principles should be applied to control external dose from uranium:	
• minimizing time in the radiation field, • maximizing the distance from the radiation source, • using shielding to reduce the radiation field, and • reducing the amount of radioactive material being used.	
3. Specific Beta Dose Control Principles	Show OT-30
Surfaces emitting beta radiation are easily shielded with plastic or other light element materials. Use of denser materials for shielding of high-energy beta	

Lesson Plan	Instructor's Notes

radiation may produce bremsstrahlung X rays and should be avoided.

Beta dose to the lens of the eye can be reduced by using safety glasses. Safety glasses are commonly worn for industrial safety concerns in areas where uranium is handled. Heavy rubber or leather gloves are effective in reducing the skin dose to the hand, but their use must be balanced against other safety concerns, such as hazards from machinery or loss of manual dexterity.

Industrial safety concerns in a uranium facility may be more hazardous to personnel than exposure to radiation. Professional radiological control personnel evaluate the process in the workplace to ensure workers receive the maximum overall protection from all hazards, not only radiological hazards. This is generally done in cooperation with industrial safety and industrial hygiene personnel.

Lesson Plan	Instructor's Notes
IV. MODULE 104 - Internal Dose Control	Show OT-31
A. Objectives	Highlight the specific internal exposure hazards and controls at your facility.
EO6 Identify the modes of entry into the body for uranium.	
EO7 Describe the measures taken to control intakes of uranium, including special radiological surveys and techniques, instruments, and release of materials.	
B. Internal Exposure to Uranium	Show OT-32
As discussed in Module 101, the primary biological hazard is the potential for uranium to be taken into the body. This exposure may result in heavy metal poisoning, including kidney damage (for acute exposures), or an increased cancer risk (for chronic exposures). Uranium may enter the body through inhalation, ingestion, absorption through the skin, or injection into the bloodstream, such as from contamination of an open wound.	
The most common route of entry is inhalation, but much of the material inhaled does not stay in the lungs. The lungs and related air passages constantly work to remove all the dust we breathe, including dust that contains uranium. The dust expelled from the lungs but not exhaled is swallowed, so some of the inhaled uranium ends up in the digestive tract.	
The amount of uranium retained in the lungs depends a great deal on the size of the particle breathed. The smallest particles tend to be exhaled or absorbed into the bloodstream, while the largest particles are usually removed before they	

Lesson Plan	Instructor's Notes
reach the lung. Uranium retained in the lungs may remain there or be absorbed into the bloodstream. Part of the uranium passing through the digestive tract may also be absorbed in the bloodstream. Uranium in the bloodstream is either transferred to various organs or excreted via the urine.	
The enrichment of the uranium in its ^{235}U isotope also plays a role in determining whether the radiological or the chemical effects are the limiting factor. For acute exposures, chemical toxicity is limiting up to 39% enrichment. Beyond 39%, the effective dose equivalent becomes limiting. For chronic exposures, chemical toxicity is more limiting up to 1.3% enrichment. Beyond 1.3%, the effective dose equivalent becomes limiting.	
C. Internal Dose Measurements	Highlight the internal exposure measurements used at your facility.
Once in the body, the presence of uranium can be detected using indirect radioactivity measurements, direct radioactivity measurements, or both.	
At one time, it was not possible to detect internal uptakes of uranium or certain other radioactive materials at levels below the point at which the annual limit for exposure (5 rem) was received. Any measurable intake of uranium was therefore considered to be unacceptable. Improved analytical and calculational techniques have now made it possible to measure uranium concentrations resulting in exposures of about 10 mrem with a reasonable degree of accuracy. The estimation of low-level internal exposure to uranium is no longer a matter for inordinate concern.	

Lesson Plan	**Instructor's Notes**

1. Indirect or *In Vitro* Measurement

Bodily processes will, to some degree, eliminate uranium taken into the body. How effective the body is at eliminating the uranium, and how long the process takes, depends upon individual metabolism and the chemical form of the uranium. For example, uranium hexafluoride contains uranium that is chemically bound to fluorine and is more easily eliminated than uranium metal or uranium dioxide.

Indirect measurements are made by sampling material eliminated by the body for the presence of uranium. It is possible to analyze both feces and urine for the presence of uranium, but due to the ease of collection and handling, the most common method used is urinalysis.

2. Direct or *In Vivo* Measurement

Direct measurements are performed using whole body counters or lung counters. These instruments detect gamma and X rays emitted from radioactive material inside the body. For example, the ^{235}U and uranium-234 (^{234}U) isotopes of uranium present in enriched uranium emit X rays that can be detected. Alpha and beta radiation emitted by material inside the body is shielded by body tissue and cannot be detected.

Direct measurement is useful for detecting uranium that is not easily eliminated by the body. This

Lesson Plan	**Instructor's Notes**
method may also be used to estimate an internal dose. Because of the very low energy and intensity of gamma radiation emitted from depleted uranium, direct measurements are not effective in detecting depleted uranium in the body.	
D. Internal Dose Reduction and Control Techniques	
The hierarchy for minimization of internal dose is given in the RCM, Article 316. Engineering controls should be the primary method of minimizing airborne contamination and internal exposure to workers, where practicable. Administrative controls, including access controls and specific work practices, should be used as the secondary method to minimize internal exposure. If the potential for airborne radioactivity still exists after engineering and administrative controls have been applied, respiratory protection should be considered. Other specific controls, such as stay times, worker safety, comfort, and efficiency, are also discussed in Article 316.	
The internal exposure resulting from uranium entering the body can be properly controlled by appropriate facility and equipment design, contamination control procedures, and protective clothing. A bioassay monitoring program to determine the amount of uranium taken into the body is also an integral part of internal exposure control.	

Lesson Plan	Instructor's Notes
1. Contamination Control Philosophy	Show OT-33
The control of contamination in the work place is a significant part of the overall radiological protection program at uranium facilities. Proper contamination control will: • limit internal exposure by minimizing the ingestion, inhalation, absorption, and injection of uranium; • limit external dose from uranium and its radioactive decay products; and • prevent the spread of radioactive materials into uncontrolled areas.	
2. Contamination Control Methods	Show OT-34
Because uranium is relatively less hazardous than some other radioactive materials, such as plutonium, some people can develop an overly relaxed attitude to uranium; in effect saying, "It's *only* uranium." Care must be taken to avoid this attitude, and to control uranium contamination in compliance with regulations, policies, and procedures. Uranium contamination can be effectively controlled by: • an evaluation of activities likely to generate or spread contamination, • use of containment devices to confine contamination as close to the source as possible,	

Lesson Plan	Instructor's Notes

- control and monitoring of airborne contamination as it is generated,
- minimizing the size and number of contaminated areas by using effective decontamination methods,
- control of movement of equipment and personnel into and out of contaminated areas,
- use of personal protective equipment, and
- effective contamination monitoring.

a. Evaluation of Work Activities

Work activities that involve the destruction of surfaces, such as grinding, machining, filing, or cutting, can easily create and spread contamination. Operations such as welding, burning, heating, etc. can alter the physical and/or chemical state of uranium compounds that are on the surfaces of equipment. Work activities such as these should be evaluated and steps taken to minimize the spread of surface contamination, personnel contamination, and airborne contamination. If possible, alternative methods for completing the task should be considered.

b. Use of Containment Devices

Whenever activities that may generate loose contamination are planned, consideration should be given to using containment devices to control the contamination to an area as

Lesson Plan	Instructor's Notes
close to the source as possible. Such devices include glovebags, gloveboxes, and tents.	
c. Control and Monitoring of Airborne Contamination	Show OT-35
Uranium contamination is relatively dense (heavy) so it is not easily stirred up into the air and quickly settles out when disturbed. Therefore, it is unlikely that significant airborne contamination will result from normal activities (such as walking) in areas contaminated with uranium. It is possible for airborne contamination to result from activity that vigorously disturbs the surface, such as sweeping, grinding, welding, and direct, high-volume air flow. Failure to control airborne contamination could result in inhalation of the contamination and spread of contamination to other areas.	
Control of airborne contamination should include:	
• an evaluation of activities that are likely to cause contamination to become airborne, • engineered controls such as installed or portable ventilation with High Efficiency Particulate Air filtration systems (HEPA systems) to remove contamination from the	

Lesson Plan	Instructor's Notes
air at a point as close to the source as possible, • physical barriers (e.g., pipes, gloveboxes, etc) and pressure differential zones, • use of alternate work activities or equipment that is less likely to generate airborne contamination, • air sampling to track airborne contamination levels, and • using respiratory protection to minimize internal dose of the worker.	
Monitoring for airborne contamination can take several forms: • long-term, low-volume air samples that provide an average of the airborne concentration over a given time; • short-duration, high-volume air samples taken in the breathing zone of a worker during work activities likely to generate airborne contamination; • low-volume (about 2 liters per minute) breathing zone samples from personal air monitors; and [Note: A liter is approximately the same volume as a quart. Use the concept of a 2-liter soda bottle to discribe the quantity.] • continuous air monitors that track airborne contamination levels over time and can be set to alarm if a specified level is reached.	Discuss the airborne contamination limits and monitoring methods in use at your facility. Airborne contamination measurments may be described in terms of Derived Air Concentrations (DACs) in order to compare with regulatory limits. One DAC is the airborne concentration that equals the Annual Limit on Intake divided by the volume of air breathed by an average worker for a working year of 2000 hours (assuming a breathing volume of 2400 m^3. DAC values are found in Appendices A and C of 10 CFR 835. The Annual Limit on Intake

Lesson Plan	Instructor's Notes
It is important that air samples represent the actual airborne contamination levels breathed by the worker so that accurate intakes may be estimated. Air monitoring is also used to detect loss of containment. It is important to ensure sample volumes and methods allow detection of airborne contamination levels below the level of concern.	is the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year that would result in a committed effective dose equivalent of 5 rems or a committed dose equivalent of 50 rems to any individual organ or tissue.
d. Minimization of Contamination Areas	
Loose contamination on work surfaces can result in contamination of shoes, clothing, and skin and thereby result in the potential for tracking of contamination into uncontrolled areas.	
This potential can be reduced by:	
• minimizing the size and number of contamination areas, • using disposable work surfaces (such as covering a benchtop with plastic) when performing work that is likely to generate contamination, and • promptly decontaminating work surfaces (good housekeeping).	

Lesson Plan	Instructor's Notes

e. Control of Movement of Equipment and Personnel

The risk of spreading contamination to an uncontrolled area is directly related to the amount of equipment moved and the number of personnel exiting the contamination area.

The risk of spreading contamination can be reduced by minimizing the movement of equipment and tools into and out of contaminated areas by using dedicated tools and equipment, and by performing as many work activities as practical outside contaminated areas.

Besides reducing the spread of contamination, these practices save money by:

- reducing the number of personnel requiring training,
- reducing the cost of decontaminating and surveying tools and equipment,
- reducing the cost of protective clothing used, and
- minimizing the production of radioactive waste.

Lesson Plan	Instructor's Notes
f. Protective Equipment	
i. Protective Clothing	Show OT-36
Use of protective clothing (PC) in contaminated areas will minimize the potential for skin contamination and ingestion of uranium. The choice of PC garments will be based on the type of job and the form of contamination hazards. Protective clothing should not be worn in uncontrolled areas such as lunch rooms.	Discuss your facility specific protective clothing requirements.
Protective clothing commonly worn in the nuclear industry can also provide beta dose reduction. Gloves are especially helpful in reducing beta dose to the hands while handling uranium.	
Contamination build-up inside work gloves has lead to unacceptable hand doses in some facilities. Reuse of leather or cloth gloves should be reviewed carefully because of such buildup. Workers should wear thin, protective gloves inside the heavy gloves.	

Lesson Plan	Instructor's Notes
ii. Respiratory Protection Respiratory protection equipment is used to provide protection from airborne hazards that may be encountered in the work environment. Respirator use is based on the level of airborne contamination known to exist or expected to be produced from the work to be performed. Respiratory protection may also be required for hazards present in an area other than radioactive airborne contamination. Health and safety groups should coordinate the use of respiratory protection requirements based on all hazards present. If a worker finds a conflict in respiratory protection requirements, he or she should not enter the work area until the conflict is resolved and the appropriate respiratory protection equipment is available.	

Lesson Plan	Instructor's Notes
g. Special Radiological Surveys and Techniques for Contamination Monitoring	Highlight the personal contamination limits and monitoring techniques in use at your facility. Refer the students to and discuss the guidance specified in the RCM Appendix 3D.

g. Special Radiological Surveys and Techniques for Contamination Monitoring

i. Alpha Monitoring

As workers at a uranium facility, you will likely perform self-monitoring for the presence of radioactive contamination.

If you recall from the general characteristics of uranium, it primarily decays by emitting an alpha particle. Many uranium decay products also decay by emitting alpha particles.

Alpha particles are highly charged and will only travel about 2 inches in air. Alpha particles are also stopped by the dead layer of skin. This means that alpha particles external to the body are not a health concern. It also means that alpha particles are hard to detect because the detector must be close to the source of the material emitting the alpha particle.

There are many detector types available for detecting alpha contamination. Two of the most

Lesson Plan	**Instructor's Notes**

commonly used types are scintillation detectors and gas proportional counters. A thin window Geiger-Mueller (GM) detector, such as a pancake probe, will also detect a small portion of the alpha radiation emitted.

ii. Beta-Gamma Monitoring

Proportional counters and GM detectors are well suited for detecting beta-gamma radiation emitted by radioactive decay products in the uranium chain. Beta-gamma radiation travels further than alpha radiation and is easier to detect. For natural, depleted, and lower levels of enriched uranium, the ability to measure uranium by detecting the beta-gamma radiation from the uranium and its radioactive decay products is about five times more sensitive than by alpha monitoring alone.

Many surfaces that could be contaminated are porous. If the uranium contamination is in the pores of the material or the surface

Lesson Plan	Instructor's Notes
of the material is wet, the alpha radiation will be blocked. Under these circumstances, beta-gamma monitoring is the only means of detecting the contamination.	
iii. Monitoring Techniques	
When performing personnel monitoring it is very important to keep the detector (i.e., the probe) close to the surface being monitored and to move the detector slowly. If the detector is not held close to the surface being monitored, the alpha particles may not reach the detector. If the detector is moved too quickly across the surface, the electronics in the instrument will not have time to respond to indicate the amount of radioactive contamination present.	
The general method for personnel scanning for alpha contamination is to scan at approximately 2 inches/ sec at a distance of approximately ¼ inch. For personnel scanning for beta contamination, it is recommended to scan at 2 inches/ sec at a distance of ½ inch. However, the surface being surveyed	Discuss surface monitoring techniques based on the audience makeup. For example, general employees or radiation workers may only be concerned with personnel surveys, while radiological control technicians may be concerned with equipment

Lesson Plan	Instructor's Notes
(i.e., soil, building surfaces, equipment, personnel), the scanning speed, and the instrument response time will determine the level of contamination that can be detected.	and building surface surveys as well as personnel surveys.
Failing to survey properly can have the same results as not surveying at all. Contamination may go undetected and may be tracked out of the radiological area. Once outside the radiological area, the contamination may be transferred from surface to surface. This transfer of contamination could result in uranium ending up inside your body, the body of a co-worker, or even the bodies of your family members and friends. The potential for spreading undetected contamination should always be kept in mind when performing self-monitoring.	
iv. Interference from Radon	
One of the problems encountered when monitoring for contamination is interference from radon and its decay products.	

Lesson Plan	**Instructor's Notes**
Radon is a radioactive gas that occurs naturally in the environment. It decays by alpha emission in the first of a series of very short half-life radionuclides that decay by alpha or beta-gamma emission.	
There is a simple, inexpensive alternative to determine if the contamination is due to radon. The effective half-life for radon radioactive decay products is about 30 minutes, compared with the millions of years it takes for uranium to decay. The simple way to determine if contamination is due to radon is to wait and see if it goes away. The sample is recounted after the radon has an opportunity to decay to lower levels. The count rates are compared, and if the count rates are significantly different, radon is the most likely reason for the higher initial count rate.	
h. Special Radiological Surveys and Techniques for Release of Materials with the Potential for Uranium Contamination	Highlight the radioactive contamination limits used for release of materials and equipment at your facility. Also discuss the facility specific methods for surveying such
The alpha contamination detection problems mentioned in monitoring personnel for	

Lesson Plan	Instructor's Notes
contamination also apply to monitoring material. An added problem is that uranium contamination may be located in areas not accessible to survey.	equipment. Refer to DOE Order 5400.5 (as applicable).
DOE requires that materials used in Contamination Areas, High Contamination Areas, and Airborne Radioactivity Areas that are being released for unrestricted use have accessible surfaces surveyed. Materials with inaccessible surfaces having a potential for internal contamination shall not be released without evaluating the material on a case-by-case basis to ensure internal contamination does not exist.	
DOE values for release of uranium-contaminated materials are higher than DOE values for release of materials contaminated with some other radioactive nuclides found in the DOE system, such as plutonium. The difference in these values is due to the relative health risk from exposure to uranium contamination compared with these other nuclides.	
Release of materials with the potential for uranium contamination shall only be performed by personnel who are trained and authorized to do so. The site radiological	Emphasize that this training alone does not qualify individuals to survey and release materials.

Lesson Plan	Instructor's Notes
control organization is responsible for designating and training these individuals.	
i. Bioassay Monitoring	
Bioassay monitoring, or measuring the amount of radioactivity inside the body, can also be a way of determining if there has been a loss of control of uranium contamination. For example, if a person who works in an area with a relatively low airborne radioactivity concentration and shows an intake consistent with a higher airborne radioactivity concentration, there may have been a previously undetected loss of airborne contamination control. Routine bioassay monitoring will assist in making these determinations.	

Lesson Plan	Instructor's Notes
V. MODULE 105 - Criticality Safety	Show OT-37
A. Objectives	
EO8 Describe the criticality safety control measures for uranium, including inventory control measures. EO9 Identify criticality monitoring techniques used with uranium.	NOTE: The training material in this module is not a substitute for criticality safety training.
B. Explanation of Criticality	Show OT-38
Uranium is a fissionable material, which means that it can undergo nuclear fission. Nuclear fission is a process in which a very heavy unstable atom primarily splits in two, or "fissions". When an atom fissions, one large atom primarily becomes two smaller atoms, between one and seven neutrons are given off, and a great deal of energy in radiation and other forms, such as the kinetic energy of the fission fragments, is released.	Energy given off during fission is approximately 200 MeV.
Some unstable atoms, such as ^{235}U, undergo a small amount of fission without any outside influences. This small amount of spontaneous fission does not present a significant hazard on its own, but the neutrons from this fission may be absorbed by other fissionable atoms. When an atom of fissionable material absorbs a neutron, the already unstable atom gains additional energy and becomes even more unstable. One way the unstable atom can get rid of its excess energy is through fission.	

Lesson Plan	Instructor's Notes
When neutrons from one fission cause fission in another atom, it is called a chain reaction. If the chain reaction is self-sustaining, we call this criticality. Criticality is a self-sustaining nuclear chain reaction. This is an obvious radiation hazard because of the amount of energy given off as gamma radiation and other forms.	
C. Factors Affecting Criticality	
Criticality depends on several factors, including the enrichment of the material, the shape of the material, and surrounding materials, that may help or hinder fission. Several factors which affect the occurrence and magnitude of a criticality:	
1. Quantity of Fissile Material	
When dealing with criticality, a common question is "How much material can I work with and still be safe?" There is some amount of the fissile material needed to have a criticality. This amount is called the "critical mass."	
2. Geometry	
To avoid a criticality event, the fissile material must not be placed in a shape, or geometry, that is favorable to criticality. In general, the lower the surface-to-volume ratio is, the greater the opportunity for criticality.	For example: a solid sphere, such as a billiard ball, has a much lower surface-to-volume ratio than a thin rectangular shape, such as a piece of paper.

Lesson Plan	**Instructor's Notes**

3. Reflectors

Sometimes, neutrons that are emitted from the fissile material may run into or otherwise interact with an atom outside the fissile material and be "bounced back" or "reflected" into the fissile material. Materials such as water, graphite (a form of carbon), and beryllium are good at reflecting neutrons. If the uranium material is surrounded by these reflector materials, criticality is easier to obtain. Accordingly, it is undesirable to store fissile material where there is potential for these materials to be present.

4. Moderators

Another factor that affects criticality is the speed of the neutrons from fission. Neutrons that are traveling at about the same speed as the atoms in surrounding materials are more easily absorbed by fissile materials. Materials that slow the neutrons are known as moderators. Examples of good moderators include water and graphite.

For an example of moderation, consider ^{235}U. This uranium isotope absorbs slow neutrons (also called "thermal" neutrons; these neutrons travel at the same speed as their surroundings) with a rather high probability for absorption. However, ^{238}U only absorbs fast neutrons (those neutrons with high energies that travel faster than their surroundings). Normally fast neutrons are quickly moderated to

Lesson Plan	**Instructor's Notes**

lower energies, so that ^{238}U will not go critical under normal conditions. The fast neutrons must be moderated, or slowed, to allow ^{235}U to go critical.

5. Neutron Absorbers (Poisons)

If neutron absorbers are present (i.e., atoms and molecules with relatively high neutron absorption coefficients), these materials will remove neutrons from being available to begin or sustain criticality. Boron is an example of a frequently used neutron absorber, or "poison".

6. Concentration or Density of Fissile Material

As the concentration or density of fissile material increases, the opportunity for criticality increases because of an increased likelihood of neutron interaction with the fissile material.

7. Enrichment

Enrichment is the separation of isotopes. With uranium, enrichment is typically referred to as increasing the percentage (by weight) of the ^{235}U isotope in material to greater than that found in natural uranium.

Obviously, the enrichment of uranium plays an important role in criticality because the amount of fissile material available for criticality is greater. For

Lesson Plan	**Instructor's Notes**
example, the higher the enrichment of ^{235}U (i.e., the concentration of ^{235}U in relation to other uranium isotopes), the greater the opportunity for criticality.	
8. Volume	
The volume of material in which fissile material is in solution can also play an important role in preventing criticality. For a given concentration or density of fissile material, the amount of fissile material will increase as the volume increases.	
9. Interaction	
Neutron interaction in an array of containers of fissile material depends on geometric factors, including size, shape, and separation of the containers, as well as the size and shape of the array itself. Materials that may surround or be intermingled with the containers are also important. A close-packed array may be come critical if flooded with water, which will thermalize neutrons. Also, a less closely-packed array may become critical if the water is removed, allowing less neutron absorption to take place.	
D. Safety Policies and Controls	
Achieving criticality involves bringing together many factors that promote a sustained nuclear chain reaction. To avoid criticality, one should be aware of the conditions that would	

Lesson Plan	Instructor's Notes
promote a criticality for the particular materials they encounter, and avoid those conditions that promote criticality.	

1. General Criticality Safety Principles

Some things done to promote criticality safety include:

- analyzing work environments to assess the risk of criticality and eliminate likely criticality concerns;
- using carefully planned and approved procedures;
- providing specific training for those personnel working in areas where fissile materials are present; and
- implementing system design features that are favorable to criticality safety. These features include:
  - using containers with a size and geometry that will not allow criticality,
  - designing piping systems to prevent buildup of uranium and prevent criticality,
  - using materials known as poisons to absorb neutrons and prevent them from being absorbed by the uranium atoms,
  - controlling material that surrounds containers or systems containing uranium, and
  - controlling uranium inventories.

Lesson Plan	Instructor's Notes
2. Controlling Uranium Inventories	
One method to prevent a criticality is controlling uranium inventories. Inventory control involves knowing where the uranium is at the facility and the level of enrichment of the uranium. Uranium enriched in ^{235}U or the presence of ^{233}U is of concern for criticality; therefore, these are materials of concern for inventory control. Criticality is a concern for ^{238}U if fast neutrons are present.	
Loss of control of fissile material presents a threat to criticality safety at the facility and, in a worst case scenario, to national security. It is no secret that groups throughout the world are striving to become nuclear powers. Even the appearance of a loss of inventory control must be avoided to keep the public trust and assure continued operations of DOE programs. For these reasons, inventories of fissile material are closely monitored.	
3. Facility-Specific Criticality Safety Controls	Insert a presentation of facility specific criticality safety controls and procedures.
Provide facility-specific information.	

Lesson Plan	Instructor's Notes
E. Criticality Monitoring Techniques Provide facility-specific information.	Discuss criticality monitoring techniques implemented at your facility. As appropriate, discuss the requirements and use of criticality alarm systems and nuclear accident dosimeters, including personal accident dosimeters. Reference and discuss 10 CFR 835.1304, as appropriate. Show OT-39

Lesson Plan	Instructor's Notes
VI. MODULE 106 - Emergency Response for Uranium Incidents	Show OT-39
A. Objective	
EO10 Understand the facility-specific emergency response procedures involving uranium incidents.	
B. Facility-Specific Emergency Response Information	Insert a discussion on facility specific emergency policies and procedures.
As discussed previously, uranium and chemical compounds containing uranium may represent radiological, fire, chemical, and criticality concerns. Prompt, appropriate emergency response in unusual situations involving uranium is vital to worker and public safety.	

Lesson Plan	Instructor's Notes
VII. MODULE 107 - Course Summary	Show OT-40
This training course provides a basic understanding of the characteristics of uranium and the general precautions and controls needed for working in a uranium facility. After this course, participants should be aware of the following basic concepts:	Show OT-41

- physical properties of uranium
- radioactive properties of uranium
- chemical properties of uranium
- toxicological properties and biological effects of uranium on the body
- sources of uranium
- uranium operations and processes
- external dose measurements
- external dose reduction and control techniques
- internal dose measurements
- internal dose reduction and control techniques
- factors affecting criticality
- criticality safety policies and controls
- emergency response for uranium incidents at your facility

The modules included in this training provide a base of general knowledge to better understand facility-specific procedures and training.

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(Part 3 of 4)

Radiological Safety Training for Uranium Facilities

Student's Guide

Coordinated and Conducted
for
Office of Environment, Safety & Health
U.S. Department of Energy

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Course Developers

Melvin Boyd	FERMCO
Gerald Eaton	Westinghouse Hanford Company
Mike Glassic	Laborers AGC
Don Goble	Lockheed Martin Energy Systems
Alan Jeffries	Lockheed Martin Energy Systems
Bruce Nakasone	Rust Geotech
Ed Schultz	Sandia National Laboratory
Paula Trinoskey	Lawrence Livermore National Laboratory
William Ulicny	ATL International, Inc.
Jeff Warga	Information Technologies

Course Reviewers

Peter O'Connell	U.S. Department of Energy
Randy Sullivan	ATL International, Inc.
Technical Standards Managers	U.S. Department of Energy

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Table of Contents

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I. MODULE 101 - Properties of Uranium

A. Objective

EO1 Describe the physical, radioactive, toxicological, and chemical properties and biological effects of uranium.

B. Physical Properties

Uranium can be encountered as a solid, liquid, or gas, depending on its chemical form and surrounding conditions. Each of these physical forms has particular hazards. Sometimes, changing the form of uranium can lead to radioactive decay products accumulating or becoming concentrated in a particular location, such as on the surface of a liquid. The result can be an apparent increase in the radioactivity.

1. Solid

The solid forms of uranium are generally the most stable configurations. The shiny, silvery metal form is rarely seen except in a workshop when it is being machined. After machining, the surface oxidizes, typically within hours, to a hard, black surface.

After some time, depending on temperature, humidity, and alloy, the surface may change color and begin to flake. Orange or yellow colored surfaces are usually more flaky and soluble. In these forms, contamination can be more easily spread, inhaled, and absorbed into the body.

2. Liquid

Uranium melts at 1133°C, so molten uranium is unusual, except in a foundry. It has often been observed that the radioactivity appears to increase when uranium is melted. This is because radioactive decay products, such as radium and thorium, float to the surface. The density of radium is 5 g/cm^3, compared with 19 g/cm^3 for uranium; therefore, radium floats in molten uranium.

Uranium in contact or solution with water is common. The primary hazards associated with a uranium solution are criticality (for enriched uranium) and spills. Water decreases the quantity of enriched uranium required for criticality. This topic will be discussed in Module 105 - Criticality Safety.

3. Airborne Powder

A spill of any radioactive solution is a concern. As the solution evaporates, it leaves behind a radioactive residue, or powder, that can easily become airborne. Airborne uranium may be inhaled and absorbed into the bloodstream through the lungs.

4. Gas

Another form of uranium that is an inhalation hazard is the volatile UF_6, becoming a gas above 56°C. However, most uranium daughters are not volatile, and so can accumulate in storage cylinders. When the volatile UF_6 is extracted, the nonvolatile daughters remain in the cylinder, resulting in the buildup of residual radioactivity. However, in the case of uranium-232 (^{232}U), uranium-235 (^{235}U), and uranium-238 (^{238}U), each of these uranium isotopes has a radon daughter. Radon is a gas at all but very low temperatures; therefore, if the radon escapes, the subsequent daughters can accumulate in closed or poorly ventilated areas.

In some situations, pressure from volatilized UF_6 gas can build up in small volumes such as a sealed container or a pipe run between two valves. Line breaks and leaks will cause a release of the UF_6. As the escaping UF_6 gas cools, it becomes particulate, which may have a suffocating effect on any nearby workers.

Another reason for pressure buildup is alpha particles emitted in radioactive decay eventually becoming inert helium gas. The amount is only significant for high specific activity forms of uranium. For example, a sample of 99% uranium-233 (^{233}U) with 1% ^{232}U creates approximately its own volume of helium gas every year. Sealed containers must include adequate gas space or be fitted with pressure release valves. Once the pressure is relieved, the low-pressure helium gas is harmless.

Hydrogen gas is generated from uranium in water, and this may also produce a pressure buildup situation. Because the hydrogen buildup may also be a fire hazard, it is discussed later in this module in the Chemical Properties section.

C. Radioactive Properties

Uranium in its pure metal form is a silvery, gray metal and is the heaviest naturally occurring element. There are 18 separate isotopes of uranium. Isotopes are elements that have the same number of protons, but different numbers of neutrons. For example, ^{235}U has 92 protons with 143 neutrons and ^{238}U has 92 protons with 146 neutrons.

Uranium is radioactive. Partially because of its size, the nucleus of a uranium atom is unstable. It reduces its size either by alpha particle emission or by nuclear fission, in which the uranium nucleus splits, primarily, into two smaller fission products. Both processes release energy, which can be helpful or harmful depending on how they are controlled.

All isotopes of uranium are fissionable, which means they can be fissioned by fast neutrons. Two isotopes, ^{233}U and ^{235}U, are fissile, which means they can also be fissioned by slow (thermal) neutrons. A fissile material can be involved in a criticality accident, resulting in the release of a lethal amount of radiation. Criticality is discussed in more detail in Module 105 - Criticality Safety.

The primary isotopes of uranium are all long-lived alpha emitters. However, several other radionuclides can be radiologically significant at uranium facilities, depending on the history of the uranium materials and the processing. These other radionuclides include the following beta emitters: ^{234}Th, ^{234m}Pa, ^{231}Th, and ^{99}Tc. The degree of enrichment also affects the controls that are required for external radiation exposure because of the increase in the amount of gamma-emitting ^{235}U that is present. The uranium daughter products may also include some low-energy gamma and x-ray radiation. For example, the daughter products of ^{232}U represent a potential gamma-emmission hazard.

Although there are several isotopes of uranium, only three exist naturally, and all three are radioactive. See the table below for half-lives and natural percent abundance for important uranium isotopes in the nuclear fuel cycle.

ISOTOPE	HALF-LIFE	NAT. ABUND.	IMPORTANCE
^{232}U	70 y	0%	An unwanted byproduct of ^{233}U production in a breeder reactor. Due to its much shorter half-life, ^{232}U contributes most of the radioactivity in samples of ^{233}U.
^{233}U	1.6×10^{5} y	0%	Manufactured by irradiating ^{232}Th with neutrons. It is a criticality hazard because it is fissile.
^{234}U	2.5×10^{5} y	0.0055%	A decay product of ^{238}U. It is concentrated with ^{235}U during enrichment. Highly enriched uranium contains about 1% ^{234}U. Most of the radioactivity of enriched uranium is from the ^{234}U.
^{235}U	7.1×10^{8} y	~0.7%	Fissile with slow neutrons; therefore, it is of primary interest for reactors and weapons. If not handled safely, an accumulation of ^{235}U could become critical.
^{236}U	2.3×10^{7} y	0%	Some ^{235}U is converted to ^{236}U in reactors. It is also present in reprocessed reactor fuel.
^{238}U	4.5×10^{9} y	~99.3%	The most abundant uranium isotope. It is fissionable with fast neutrons; however, it is not fissile (i.e., with thermal neutrons) so it is not a criticality hazard.

As uranium goes through radioactive decay, it produces other radioactive elements known as radioactive decay products (also called progeny or daughter products). These radioactive decay products are also radioactive and have to be taken into account for radiological protection purposes.

Both alpha and beta particles are emitted as part of decay series. For example, ^{238}U decays by alpha emission to ^{234}Th; ^{234}Th decays by beta emission to ^{234m}Pa; and so on, until stable ^{206}Pb is finally reached.

1. Decay Series

Uranium has two naturally occurring decay series: the "actinium" series, which has ^{235}U as its parent; and the "uranium" series, which has ^{238}U as its parent. Many of our everyday encounters with radioactivity come from these decay series; examples are radon gas and radium.

There are also man-made isotopes of uranium - ^{232}U and ^{233}U. The decay products from these radionuclides must be considered in the implementation of a radiological control program at a facility where these uranium nuclides are present.

2. Criticality

Uranium is a fissionable material, which means it can undergo nuclear fission. Nuclear fission is a process in which a very heavy, unstable atom splits in two, or "fissions". When an atom fissions, one large atom primarily becomes two smaller atoms, between one and seven neutrons are given off (which may cause fission in nearby atoms), and a great deal of energy is given off as radiation and in other forms, such as kinetic energy of the fission fragments. The radiation created could result in the creation of radiological areas, such as High or Very High Radiation Areas. Nuclear criticality associated with uranium will be discussed in greater detail later in the lesson.

D. Chemical Properties

Uranium is chemically reactive. It burns in air like magnesium; it is toxic like lead; and it forms a large variety of chemical compounds. All the isotopes of uranium have the same chemical reactivity, and all can be made into the many different physical and chemical forms discussed in this section.

1. Fire

Uranium is a metal that will sustain a burning reaction (similar to a magnesium flare). The potential for a fire is greatest when the uranium is in a finely divided form, such as milling chips or filings. In this form, uranium can undergo spontaneous ignition. Uranium metal is often machined to provide a useful end product, and milling chips and filings are unavoidable byproducts.

Precautions must be taken to prevent chips and filings from igniting. One precaution is submersing the chips and filings in water or a mineral oil. Storage in water produces hydrogen gas due to a chemical reaction. To prevent the hydrogen gas from reaching an explosive concentration, and to prevent a pressure buildup, containers must be vented. Incidents have occurred where container lids have been blown off by unexpected gas pressure buildup.

Once uranium starts to burn, it is extremely difficult to extinguish. None of the typical extinguishing methods, such as water, carbon dioxide, or halon, is effective in fighting uranium fires. In fact, halon may be explosive and produce toxic fumes if used directly on the fire.

Normally, small fires may be put out by using MET-L-X powder, which is a mixture of sodium chloride (table salt) and potassium carbonate (baking powder). When spread over the burning metal in significant quantities, MET-L-X starves the fire of oxygen.

Larger fires, such as with storage drums, are more difficult to extinguish. Submersion in water will eventually work once the metal cools down. However, continuous water addition is necessary to make up for losses due to boiling and evaporation.

2. Toxicological/Biological Effects

The principal entry of uranium into the human system is due to either inhalation or ingestion. Inhalation occurs either from release of volatile uranium compound or from suspension of volatile uranium-laden aerosols. Ingestion can occur when the uranium is introduced into water for consumption or the food chain by plant uptake. When uranium is either ingested or inhaled, it is removed from the body with a biological half-life varying between 6 and 5000 days, depending on which organ has become contaminated. Uranium tends to concentrate in the kidneys and the bones. Additionally, if inhaled, the lungs are exposed. Internal exposure to uranium is controlled by limiting the ingestion and inhalation of this element. These methods, along with measurement techniques, are discussed in Module 104.

Most heavy metals, such as uranium, are toxic to humans depending on the amount introduced into the body. For short-term (acute) exposures, the toxicological effects are the primary concern, and acute exposures to significant amounts of uranium may result in kidney damage. However, as the enrichment of the uranium in the ^{235}U isotope increases, so too do the effects of radiation exposure in relation to toxicological effects.

Past industrial experience has proven that if there is a long-term exposure of small amounts of uranium (chronic exposure), the radiological effects are the primary biological concern. In fact, for chronic exposures, a development of tolerance against the toxicological effects may occur. The principal radiological hazard associated with uranium is due to the relatively high energy alpha particles its radionuclides and daughters emit. A chronic exposure to these radionuclides result in an increased risk of cancer, typically in the bones, kidney, and lungs, since these are the organs where uranium is deposited.

3. Chemical Reactivity

The chemistry of uranium is complicated. For example, uranium forms several oxides: UO, UO_2, UO_3, and UO_4. In general, a sample of uranium oxide will include a mixture of several of these. For example, U_3O_8 is sometimes written as $(UO_2) \cdot 2(UO_3)$.

The lower oxidation states, UO_2 and U_3O_8, tend to be dark brown or black. The higher oxidation states, UO_3 and UO_4, are generally orange or yellow, especially in solution or if water or crystallization are present (e.g., $UO_4 \cdot 2H_2O$). Furthermore, the higher oxides usually flake off more easily and are usually more soluble in water. Being flaky, they are more easily inhaled. Being more soluble, they are more easily absorbed into the body.

Uranyl compounds, such as uranyl nitrate, or $UO_2(NO_3)_2$, are chemical forms of uranium that are often found in solution with water. They are generally yellow in color and are used in criticality experiments.

Uranium reacts readily with air and water. For example, when uranium is machined, small chips catch fire from the heat of the machining process. Shavings placed in water react to produce hydrogen gas. The surfaces quickly oxidize to a hard black coating that is at first protective; however, under adverse conditions, it corrodes and flakes.

Uranium also reacts with hydrogen or tritium gas to form uranium hydride (UH_3). Uranium "beds" are commonly used to store tritium.

Uranium hexafluoride (UF_6) reacts in moist air to produce hydrogen fluoride (HF) gas, which is corrosive and can damage the lungs if breathed. Inhalation of HF has resulted in fatalities following UF_6 releases.

The chemical form of uranium is dependent on its intended use and its stage of production. For example, UF_6 is used during the enrichment process, and UO_2 is used as nuclear fuel. When handling uranium compounds, the possibility of chemical reactions must not be overlooked.

II. MODULE 102 - The Nuclear Fuel Cycle

A. Objectives

EO2 Identify the sources and uses of uranium.

EO3 Identify the various processes involved in the nuclear fuel cycle.

B. Importance of Uranium

Uranium is a naturally occurring element used primarily for producing energy with nuclear reactors and developing nuclear weapons. It is also used for armor plating (depleted uranium), radiation shielding, and counterweights.

Historically, uranium was used for hundreds of years to color glass and as a glaze for tile and pottery. Bright orange "Fiesta-ware" dinner plates were prized for their color without any awareness of their radioactivity. These plates are no longer produced, but are now collectors' items among those in the nuclear industry and others. Typically, the dose rate is about 5 mrem/hr (0.05 mSv/hr) on contact with these plates.

The original discovery of radioactivity involved uranium. In 1896, Henri Becquerel discovered that uranium would cause photographic film to become fogged because of radioactive emissions. Some of these emissions were even more penetrating that the "X rays" that Wilhelm Roentgen had discovered a year earlier.

Later investigators, such as Marie Curie, isolated other radioactive elements from uranium ores. These elements are produced from the radioactive decay of uranium. The radioactive emission of an alpha particle causes uranium to change into thorium. Thorium goes on to decay to other elements, and so on, until a stable element such as lead is reached.

Radium and radon are the two most well-known radioactive decay products of uranium. Radium was once used for luminous instrument dials and other products. Radon is a heavy radioactive gas that can accumulate in buildings and mines. Typically, these radioactive decay products are more hazardous than the uranium itself.

The importance of uranium increased dramatically with the discovery of nuclear fission in 1938, the production of plutonium in 1940, and the construction of the first reactor in 1942 under the direction of Enrico Fermi. These accomplishments led to the Manhattan Project, in which uranium was enriched at Oak Ridge or converted into plutonium at Hanford. These products were used to assemble the first atomic bombs at Los Alamos in 1945.

After the end of World War II in 1945, the importance of uranium remained high. Production of uranium and plutonium for "atomic" or "nuclear" weapons continued throughout the Cold War. In addition, nuclear reactors were built for the propulsion of naval submarines and ships, and for the commercial production of electricity. Now, most of the world's production of uranium is used for nuclear reactors.

C. Sources of Uranium

Uranium is found in the earth's crust and is mined as ore. The average concentration is 2 parts per million (ppm) in the crust and less than 2 parts per billion (ppb) in the oceans. During the 1960's and 1970's, a program titled the Natural Uranium Resource Exploration was funded by the government to identify the locations of desirable uranium ore throughout the United States. It was determined that the most desirable locations of uranium are in the Colorado Plateau, the Wyoming Basin, and the flanks of the Black Hills in South Dakota. In those locations, the uranium concentration is much higher than 2 ppm. Uranium is also found on the African Continent. The ore is removed from either shallow open pits (less than 300-foot, or100 m, depths) or underground mines (greater than 300-foot depths). The typical uranium content of the ore is 0.15 - 0.3 percent and is in the form of U_3O_8, which is called "yellowcake." Uranium is also found in secondary minerals in the following forms: complex oxides, silicates, phosphates, and vanadates.

D. Uranium Operations and Processes

Uranium processing is dependent upon the desired product, but it generally involves the following cycle:

- mining and milling,
- conversion,
- enrichment,
- fabrication,
- use,
- waste disposal/storage, and
- decontamination and decommissioning.

1. Uranium Mining and Milling

After removal from the mine, the uranium ore is milled to extract the yellowcake. This involves the following process:

a. The ore is crushed, ground, and mixed with water to prepare for chemical processing.

b. The crushed ore and water mixture is mixed with chemicals to separate the yellowcake from the ore. This separation process is called "leaching." The resultant products include a slurry of yellowcake ready for additional processing and a mixture of low-grade crushed rock and sand called "mill tailings."

Only about 3 percent of the actual material removed from the mine ends up as yellowcake, which means that millions of tons of mill tailings are leftover. Yellowcake contains 70-90% by weight of uranium oxides. The leftover mill tailings are a concern because they still contain some of the uranium ore . Additional hazards exist due to the chemicals added.

It is estimated that the uranium milling in the United States left approximately 138 million tons of mill tailings covering about 3,000 acres of land.

c. The yellowcake slurry is then purified by either ion exchange or solvent extraction.

d. Following purification, the yellowcake slurry is dried, forming a concentrated yellowcake compound that contains 75 - 98 percent uranium. The yellow color is caused by the addition of leaching chemicals and their eventual removal during the drying step. The final color can range from yellow to orange to black depending on the chemicals used and the drying temperature.

The final color is a good indicator of solubility, and thus of biological effects if uranium in this form is taken into the body. Less soluble uranium compounds tend both to remain in the body longer and to be darker in color. More soluble uranium compounds are removed from the body more quickly by normal body functions, and tend to be lighter in color.

2. Conversion

At this stage in the nuclear fuel cycle, the yellowcake is converted into uranium hexafluoride (UF_6) for enrichment. This is accomplished by:

a. Conversion of yellowcake to pure uranium trioxide (UO_3), called "orange oxide" or "orange salt," by solvent extraction and follow-up drying.

b. Conversion of UO_3 to uranium dioxide UO_2.

c. Conversion of UO_2 to uranium tetrafluoride (UF_4) by hydrofluorination (addition of hydrogen fluoride gas). This product is called "green salt."

d. Reacting the UF_4 with fluorine gas (F_2) to form uranium hexafluoride (UF_6), which is a volatile form ready for enrichment. The UF_6 is a solid at room temperature but readily becomes a gas when heated above 56°C.

3. Enrichment

The enrichment process is necessary to increase the percentage of the ^{235}U isotope in the uranium to make it suitable for reactor fuel. Natural uranium contains 0.7% ^{235}U. Typically, enriched uranium contains 2-4% ^{235}U. Other uses may require much higher concentrations up to, or even greater than, 90% ^{235}U. Depleted uranium, which is left over after the enrichment process, has an abundance of about 0.2% ^{235}U.

The methods used to enrich uranium include:

a. *Gaseous Diffusion*

Gaseous diffusion is based on principles of gas laws. The UF_6 gas is forced through converters by large compressors. The converters contain many tubes made of a special barrier material that is porous. The $^{235}UF_6$ molecules are lighter than the $^{238}UF_6$ molecules and bounce against the porous barrier more frequently. The $^{235}UF_6$ has a greater chance of passing through the barrier, resulting in a slightly richer ^{235}U content. It may take as many as a thousand passes to obtain the desired degree of enrichment.

b. *Laser Processes*

The Atomic Vaporization Laser Isotope Separation (AVLIS) involves vaporization, selective ionization of one isotope, and subsequent electrical separation. Currently, no DOE production plants exist which use this technology.

c. *Nozzle Separation*

The nozzle separation process is based on the different speeds of ^{235}U and ^{238}U compounds when they are injected through a nozzle into a small chamber.

d. *Centrifugal Separation*

Centrifugal separation is based on heavier compounds migrating to the outside when spun at a high rate of speed.

The uranium left over from the enrichment process is mostly ^{238}U, with a reduced amount of ^{235}U (usually 0.2% by weight). This byproduct is called "depleted uranium" and has additional uses such as radiation shielding, armor plating, and ammunition.

During World War II, uranium work was secret and code names were used for the different forms of uranium. Natural uranium was named "Tuballoy," a name that grew out of a cover story that the Allies were investigating alloys for high-quality tubing. Highly enriched uranium was then named "Oralloy" for "Oak Ridge Alloy," sometimes abbreviated to "Oy." Depleted uranium was once called depletalloy, but more commonly was called "D-38" since it consists mostly of ^{238}U. These historical names are sometimes still used within the DOE complex.

4. Fabrication

The last step in the nuclear fuel cycle is changing the enriched uranium into an appropriate form for fabrication. The fabrication process differs depending on the application. For fabrication of fuel elements, the process generally includes the following steps.

a. Uranium dioxide (UO_2) is produced by reacting UF_6 with water and then with a hydroxide salt.

b. The resulting precipitate is dried to form "orange oxide," which is reduced with hydrogen to form UO_2 powder.

c. The UO_2 powder is compacted into cylindrical pellets that are loaded into thin-walled tubes made of either stainless steel or an alloy of zirconium called "zircalloy."

d. Helium, an inert gas, is pumped into the tubes, which are then capped. A cluster of these tubes separated by spacers forms a reactor fuel assembly.

Fabrication of other materials, such as weapons parts, may also include materials made with uranium.

5. Uses

The primary goal of the uranium fuel cycle process is to yield enriched uranium. This product can be used for:

- power reactors,
- research reactors,
- nuclear weapons, and
- naval propulsion reactors.

There are also a number of uses for uranium metal depleted in the ^{235}U isotope, such as:

- radiation shielding,
- armor-piercing bullets,
- catalysts for chemical reactions,
- armor plating, and
- counter weights.

Depleted uranium typically is cast into ingots or billets, and then shipped to production facilities for appropriate reshaping.

6. Reprocessing

Reprocessing of spent nuclear fuel is no longer performed in this country. This information is provided for the purpose of describing how the process worked at applicable facilities.

Uranium was used in plutonium production reactors. Uranium fuel and targets were coated with aluminum or zirconium metal and placed in the reactor. As they were irradiated with neutrons, a small fraction of the uranium was converted to plutonium. The irradiated fuel was then removed from the reactor, but the plutonium and uranium had to be separated from the fission products created during irradiation.

PUREX, a chemical process for **p**lutonium and **ur**anium **ex**traction from irradiated nuclear fuel, was developed to accomplish this separation. This reprocessing was accomplished as follows:

a. Excess metal was mechanically removed to expose the fuel material.

b. The fuel was leached with acid to remove it from the cladding.

c. The uranium and other elements were separated by solvent extraction (chemical separation).

d. The uranium was converted back to UF_6 for enrichment.

7. Waste Disposal and Storage

Due to the remaining radioactive properties, the nuclear fuel cycle byproducts must be controlled and/or disposed. These byproducts can be divided into two categories—low-level waste (LLW) and high-level waste (HLW).

a. *LLW*

The RCM glossary defines low-level waste (LLW) as "Waste that contains radioactivity and is not classified as high-level waste, transuranic waste, spent nuclear fuel, or byproduct material as defined in Section 11e(2) of the Atomic Energy Act, as amended. Test specimens of fissionable material irradiated only for research and development and not for production of power or plutonium may be classified as low-level waste provided the concentration of transuranic activity is less than 100 nCi/g." LLW could be in the form of liquids, solids, or gasses. Liquid waste is usually processed to remove radioactive material and then recycled or disposed.

Solids may be volume-reduced by incineration or compaction. Soluble forms in liquid may be solidified to isolate radioactive contents.

Gases are either changed to a solid form and disposed of as a solid or compressed and stored as gases. These gases may be released after sufficient time has elapsed for decay of the radioactive component of the gas.

b. *HLW*

High-level waste (HLW) is defined in DOE Order 5820.2a as "The highly radioactive waste material that results from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid waste derived from the liquid, that contains a combination of transuranic waste and fission products in concentrations requiring permanent isolation.

HLW comes primarily from the reprocessing of spent fuel. It is typically in liquid form, and it is collected and stored in tanks. The liquid waste is then solidified (stabilized) for disposal. All HLW is ultimately to be disposed of by deep burial.

8. Decontamination and Decommissioning of Uranium Facilities

Uranium and its byproducts from the nuclear fuel cycle may present health risks due to radioactivity or chemical properties. Past and present DOE uranium facilities and their surrounding areas may contain contamination from uranium or its byproducts. DOE recognizes that they have a responsibility to restore these potentially contaminated facilities and surrounding areas to a nonhazardous condition. To accomplish this, several "remediation" programs are in place and others are developing.

Some cleanup programs include:

a. Uranium Mill Tailings Remedial Action (UMTRA) Program

This program is intended to cleanup uranium mill sites and associated "vicinity properties." It covers 24 mill sites and more than 4,800 properties throughout the Nation. The goals of the program are to reduce radon release from mill tailings to acceptable levels by burial, and to restore affected land and facilities/structures to unrestricted use.

b. Formerly Utilized Sites Remedial Action Program (FUSRAP)

This program is intended to clean up uranium-contaminated DOE contractor facilities that processed uranium ores for the Manhattan Project.

c. Surplus Facilities Management Program (SFMP)

This program covers sites that are being restored for unrestricted use.

Each cleanup project presents different types and levels of hazards to workers. Additionally, general safety hazards become a significant factor due to the types of processes and equipment used to remove the uranium-contaminated materials. Usually these projects require some level of structural decontamination and soil remediation.

III. MODULE 103 - External Dose Control

A. Objectives

EO4 Identify the radiological concerns of external exposure to uranium.

EO5 Describe the measures taken to control external exposure to uranium.

B. Alpha External Dose

Because of the relatively short range of alpha particles in dense matter, alpha radiation poses little external dose hazard. The most energetic alphas produced by naturally occurring radionuclides will barely penetrate the dead layer of skin on the human body. Little living tissue will be affected when the alpha source is external to the skin.

C. Beta External Dose

Beta doses to the skin, extremities, and the lens of the eye can be limiting in facilities which process unshielded depleted, natural, or low-enrichment uranium. Processes which separate and sometimes concentrate beta-emitting uranium daughters are not uncommon in DOE uranium facilities. Control of exposure is complicated by the fact that considerable contact work takes place in facilities which process uranium metal.

Several uranium radioactive decay products are beta emitters. Normally, most of these betas are shielded by the surrounding material or material worn as personal protective clothing (such as Tyvek). A primary radionuclide of concern is protactinium-234 in its metastable state (^{234m}Pa), a daughter of ^{238}U which produces a very high energy beta particle that can travel up to 20 feet in air. Significant beta radiation is also emitted from ^{234}Th (also a daughter of ^{238}U) and ^{231}Th (a daughter of ^{235}U). Typically, these are shielded with ½-inch of plastic.

D. Gamma and X-Ray External Dose

Although beta dose from unshielded uranium presents the most common radiation problem, storage of large quantities of uranium can create low-level gamma radiation fields (less than 5 mrem/hr). Such fields can create external exposure problems, particularly when significant numbers of people are working in adjacent areas.

In addition to gamma emissions from the uranium decay chains (^{238}U and ^{235}U), recycled fuel materials introduced back into the enrichment process will result in higher gamma radiation fields because of ^{228}Th, a gamma-emitting daughter of ^{232}U with a relatively short half-life (1.9 yr).

Larger sources of gamma radiation may exist from specific uranium processes, including unflushed UF_6 cylinders. Gamma radiation emitted from residual materials can result in gamma radiation fields of several hundred millirem per hour. This problem can be controlled by flushing empty cylinders to remove residual material.

E. Neutron External Dose

As uranium is processed in the fuel cycle, it is often chemically bonded to fluorine to create compounds such as UF_4 and UF_6. When uranium atoms in these compounds decay, they emit alpha particles that are sometimes captured by the neighboring fluorine atoms. The resulting atom is unstable and may emit a neutron to gain back its stability. The neutrons emitted can result in neutron radiation fields between 0.5 and 4 mrem/h.

The probability of spontaneous fission is small; therefore exposure is not expected. However, if fission does occur, such as in a reactor or from experiments, the neutron radiation is typically contained. Neutron radiation that is not contained is usually the result of a criticality accident, which generates potentially fatal doses of gamma radiation.

F. External Dose Measurements

The radiation from uranium that affects external dose includes beta, gamma, X-ray and neutron irradiation. An effective external exposure control program for uranium requires a variety of radiation detection instruments that are responsive to these forms of radiation. Radiation surveys should be performed on a routine basis and during events, tasks, procedures, or situations that are likely to cause radiological conditions to change. There are two general categories of measurement used for external exposure associateed with uranium, portable survey instruments and personnel dosimeters.

Gamma radiation from uranium is normally not the controlling problem. For example, the contact beta radiation field from depleted uranium is approximately 240 millirem per hour, while the contact gamma radiation field is less than 10 millirem per hour. However, significant gamma fields can exist in areas where large quantities of uranium are stored, such as a storage area for uranium contaminated soil. The accuracy and precision of survey instruments used for measurement of beta radiation fields depend on many factors which must be addressed, such as energy response and geometry factors. Accordingly, these surveys are typically conducted by Radiological Control personnel. Neutron fields from enriched uranium fluoride compounds can also add to this area of concern. Depending on the magnitude of neutron fields generated, periodic neutron dose rate measurements are made, typically by Radiological Control personnel.

Personnel dosimeters produce the data which becomes the formal or "legal" record of personnel exposure, thermoluminescent dosimeters, used in most DOE uranium facilities, provides the most accurate and precise means of measuring doses received by workers.

G. External Dose Reduction and Control Techniques

1. External Dose Control Program

The primary purpose of an external dose control program is to control dose to the individual radiation worker to below regulatory limits and administrative levels and ensuring that doses are As Low As Reasonably Achievable (ALARA). In all cases at DOE facilities, dose received by an individual shall not exceed the limits specified in Title 10 of the Code of Federal Regulations, Part 835 (10 CFR 835).

The elements of an external dose control program include:

- detecting and characterizing the beta, gamma, X-ray, and neutron radiation fields;
- measuring and/or quantifying these radiation fields;
- measuring personnel exposure; and
- determining external exposure control practices.

2. General External Dose Control Practices

These general principles should be applied to control external dose from uranium:

- minimizing time in the radiation field,
- maximizing the distance from the radiation source,
- using shielding to reduce the radiation field, and
- reducing the amount of radioactive material being used.

3. Specific Beta Dose Control Principles

Surfaces emitting beta radiation are easily shielded with plastic or other light element materials. Use of denser materials for shielding of high-energy beta radiation may produce bremsstrahlung X rays and should be avoided.

Beta dose to the lens of the eye can be reduced by using safety glasses. Safety glasses are commonly worn for industrial safety concerns in areas where uranium is handled. Heavy rubber or leather gloves are effective in reducing the skin dose to the hand, but their use must be balanced against other safety concerns, such as hazards from machinery or loss of manual dexterity.

Industrial safety concerns in a uranium facility may be more hazardous to personnel than exposure to radiation. Professional radiological control personnel evaluate the process in the workplace to ensure workers receive the maximum overall protection from all hazards, not only radiological hazards. This is generally done in cooperation with industrial safety and industrial hygiene personnel.

IV. MODULE 104 - Internal Dose Control

A. Objectives

EO6 Identify the modes of entry into the body for uranium.

EO7 Describe the measures taken to control intakes of uranium, including special radiological surveys and techniques, instruments, and release of materials.

B. Internal Exposure to Uranium

As discussed in Module 101, the primary biological hazard is the potential for uranium to be taken into the body. This exposure may result in heavy metal poisoning, including kidney damage (for acute exposures), or an increased cancer risk (for chronic exposures). Uranium may enter the body through inhalation, ingestion, absorption through the skin, or injection into the bloodstream, such as from contamination of an open wound.

The most common route of entry is inhalation, but much of the material inhaled does not stay in the lungs. The lungs and related air passages constantly work to remove all the dust we breathe, including dust that contains uranium. The dust expelled from the lungs but not exhaled is swallowed, so some of the inhaled uranium ends up in the digestive tract.

The amount of uranium retained in the lungs depends a great deal on the size of the particle breathed. The smallest particles tend to be exhaled or absorbed into the bloodstream, while the largest particles are usually removed before they reach the lung. Uranium retained in the lungs may remain there or be absorbed into the bloodstream. Part of the uranium passing through the digestive tract may also be absorbed in the bloodstream. Uranium in the bloodstream is either transferred to various organs or excreted via the urine.

The enrichment of the uranium in its ^{235}U isotope also plays a role in determining whether the radiological or the chemical effects are the limiting factor. For acute exposures, chemical toxicity is limiting up to 39% enrichment. Beyond 39%, the effective dose equivalent becomes limiting. For chronic exposures, chemical toxicity is more limiting up to 1.3% enrichment. Beyond 1.3%, the effective dose equivalent becomes limiting.

C. Internal Dose Measurements

Once in the body, the presence of uranium can be detected using indirect radioactivity measurements, direct radioactivity measurements, or both.

At one time, it was not possible to detect internal uptakes of uranium or certain other radioactive materials at levels below the point at which the annual limit for exposure (5 rem) was received. Any measurable intake of uranium was therefore considered to be unacceptable. Improved analytical and calculational techniques have now made it possible to measure uranium concentrations resulting in exposures of about 10 mrem with a reasonable degree of accuracy. The estimation of low-level internal exposure to uranium is no longer a matter for inordinate concern.

1. Indirect or *In Vitro* Measurement

Bodily processes will, to some degree, eliminate uranium taken into the body. How effective the body is at eliminating the uranium, and how long the process takes, depends upon individual metabolism and the chemical form of the uranium. For example, uranium hexafluoride contains uranium that is chemically bound to fluorine and is more easily eliminated than uranium metal or uranium dioxide.

Indirect measurements are made by sampling material eliminated by the body for the presence of uranium. It is possible to analyze both feces and urine for the presence of uranium, but due to the ease of collection and handling, the most common method used is urinalysis.

2. Direct or *In Vivo* Measurement

Direct measurements are performed using whole body counters or lung counters. These instruments detect gamma and X rays emitted from radioactive material inside the body. For example, the ^{235}U and uranium-234 (^{234}U) isotopes of uranium present in enriched uranium emit X rays that can be detected. Alpha and beta radiation emitted by material inside the body is shielded by body tissue and cannot be detected.

Direct measurement is useful for detecting uranium that is not easily eliminated by the body. This method may also be used to estimate an internal dose. Because of the very low energy and intensity of gamma radiation emitted from depleted uranium, direct measurements are not effective in detecting depleted uranium in the body.

D. Internal Dose Reduction and Control Techniques

The hierarchy for minimization of internal dose is given in the RCM, Article 316. Engineering controls should be the primary method of minimizing airborne contamination and internal exposure to workers, where practicable. Administrative controls, including access controls and specific work practices, should be used as the secondary method to minimize internal exposure. If the potential for airborne radioactivity still exists after engineering and administrative controls have been applied, respiratory protection should be considered. Other specific controls, such as stay times, worker safety, comfort, and efficiency, are also discussed in Article 316.

The internal exposure resulting from uranium entering the body can be properly controlled by appropriate facility and equipment design, contamination control procedures, and protective clothing. A bioassay monitoring program to determine the amount of uranium taken into the body is also an integral part of internal exposure control.

1. Contamination Control Philosophy

The control of contamination in the work place is a significant part of the overall radiological protection program at uranium facilities. Proper contamination control will:

- limit internal exposure by minimizing the ingestion, inhalation, absorption, and injection of uranium;

- limit external dose from uranium and its radioactive decay products; and
- prevent the spread of radioactive materials into uncontrolled areas.

2. Contamination Control Methods

Because uranium is relatively less hazardous than some other radioactive materials, such as plutonium, some people can develop an overly relaxed attitude to uranium; in effect saying, "It's *only* uranium." Care must be taken to avoid this attitude, and to control uranium contamination in compliance with regulations, policies, and procedures. Uranium contamination can be effectively controlled by:

- an evaluation of activities likely to generate or spread contamination,
- use of containment devices to confine contamination as close to the source as possible,
- control and monitoring of airborne contamination as it is generated,
- minimizing the size and number of contaminated areas by using effective decontamination methods,
- control of movement of equipment and personnel into and out of contaminated areas,
- use of personal protective equipment, and
- effective contamination monitoring.

a. Evaluation of Work Activities

Work activities that involve the destruction of surfaces, such as grinding, machining, filing, or cutting, can easily create and spread contamination. Operations such as welding, burning, heating, etc. can alter the physical and/or chemical state of uranium compounds that are on the surfaces of equipment. Work activities such as these should be evaluated and steps taken to minimize the spread of surface contamination, personnel contamination, and airborne contamination. If possible, alternative methods for completing the task should be considered.

b. Use of Containment Devices

Whenever activities that may generate loose contamination are planned, consideration should be given to using containment devices to control the contamination to an area as close to the source as possible. Such devices include glovebags, gloveboxes, and tents.

c. Control and Monitoring of Airborne Contamination

Uranium contamination is relatively dense (heavy) so it is not easily stirred up into the air and quickly settles out when disturbed. Therefore, it is unlikely that significant airborne contamination will result from normal activities (such as walking) in areas contaminated with uranium. It is possible for airborne contamination to result from activity that vigorously disturbs the surface, such as sweeping, grinding, welding, and direct, high-volume air flow. Failure to control airborne contamination could result in inhalation of the contamination and spread of contamination to other areas.

Control of airborne contamination should include:

- an evaluation of activities that are likely to cause contamination to become airborne,
- engineered controls such as installed or portable ventilation with High Efficiency Particulate Air filtration systems (HEPA systems) to remove contamination from the air at a point as close to the source as possible,
- physical barriers (e.g., pipes, gloveboxes, etc) and pressure differential zones,
- use of alternate work activities or equipment that is less likely to generate airborne contamination,
- air sampling to track airborne contamination levels, and
- using respiratory protection to minimize internal dose of the worker.

Monitoring for airborne contamination can take several forms:

- long-term, low-volume air samples that provide an average of the airborne concentration over a given time;
- short-duration, high-volume air samples taken in the breathing zone of a worker during work activities likely to generate airborne contamination;
- low-volume (about 2 liters per minute) breathing zone samples from personal air monitors; and [Note: A liter is approximately the same volume as a quart. Use the concept of a 2-liter soda bottle to discribe the quantity.]
- continuous air monitors that track airborne contamination levels over time and can be set to alarm if a specified level is reached.

It is important that air samples represent the actual airborne contamination levels breathed by the worker so that accurate intakes may be estimated. Air monitoring is also used to detect loss of containment. It is important to ensure sample volumes and methods allow detection of airborne contamination levels below the level of concern.

d. Minimization of Contamination Areas

Loose contamination on work surfaces can result in contamination of shoes, clothing, and skin and thereby result in the potential for tracking of contamination into uncontrolled areas.

This potential can be reduced by:

- minimizing the size and number of contamination areas,
- using disposable work surfaces (such as covering a benchtop with plastic) when performing work that is likely to generate contamination, and
- promptly decontaminating work surfaces (good housekeeping).

e. Control of Movement of Equipment and Personnel

The risk of spreading contamination to an uncontrolled area is directly related to the amount of equipment moved and the number of personnel exiting the contamination area.

The risk of spreading contamination can be reduced by minimizing the movement of equipment and tools into and out of contaminated areas by using dedicated tools and equipment, and by performing as many work activities as practical outside contaminated areas.

Besides reducing the spread of contamination, these practices save money by:

- reducing the number of personnel requiring training,
- reducing the cost of decontaminating and surveying tools and equipment,
- reducing the cost of protective clothing used, and
- minimizing the production of radioactive waste.

f. Protective Equipment

i. Protective Clothing

Use of protective clothing (PC) in contaminated areas will minimize the potential for skin contamination and ingestion of uranium. The choice of PC garments will be based on the type of job and the form of contamination hazards. Protective clothing should not be worn in uncontrolled areas such as lunch rooms.

Protective clothing commonly worn in the nuclear industry can also provide beta dose reduction. Gloves are especially helpful in reducing beta dose to the hands while handling uranium.

Contamination build-up inside work gloves has lead to unacceptable hand doses in some facilities. Reuse of leather or cloth gloves should be reviewed carefully because of such buildup. Workers should wear thin, protective gloves inside the heavy gloves.

ii. Respiratory Protection

Respiratory protection equipment is used to provide protection from airborne hazards that may be encountered in the work environment. Respirator use is based on the level of airborne contamination known to exist or expected to be produced from the work to be performed.

Respiratory protection may also be required for hazards present in an area other than radioactive airborne contamination. Health and safety groups should coordinate the use of respiratory protection requirements based on all hazards present. If a worker finds a conflict in respiratory protection requirements, he or she should not enter the work area until the conflict is resolved and the appropriate respiratory protection equipment is available.

g. Special Radiological Surveys and Techniques for Contamination Monitoring

i. Alpha Monitoring

As workers at a uranium facility, you will likely perform self-monitoring for the presence of radioactive contamination.

If you recall from the general characteristics of uranium, it primarily decays by emitting an alpha particle. Many uranium decay products also decay by emitting alpha particles.

Alpha particles are highly charged and will only travel about 2 inches in air. Alpha particles are also stopped by the dead layer of skin. This means that alpha particles external to the body are not a health concern. It also means that alpha particles are hard to detect because the detector must be close to the source of the material emitting the alpha particle.

There are many detector types available for detecting alpha contamination. Two of the most commonly used types are scintillation detectors and gas proportional counters. A thin window Geiger-Mueller (GM) detector, such as a pancake probe, will also detect a small portion of the alpha radiation emitted.

ii. Beta-Gamma Monitoring

Proportional counters and GM detectors are well suited for detecting beta-gamma radiation emitted by radioactive decay products in the uranium chain. Beta-gamma radiation travels further than alpha radiation and is easier to detect. For natural, depleted, and lower levels of enriched uranium, the ability to measure uranium by detecting the beta-gamma radiation from the uranium and its radioactive decay products is about five times more sensitive than by alpha monitoring alone.

Many surfaces that could be contaminated are porous. If the uranium contamination is in the pores of the material or the surface of the material is wet, the alpha radiation will be blocked. Under these circumstances, beta-gamma monitoring is the only means of detecting the contamination.

iii. Monitoring Techniques

When performing personnel monitoring it is very important to keep the detector (i.e., the probe) close to the surface being monitored and to move the detector slowly. If the detector is not held close to the surface being monitored, the alpha particles may not reach the detector. If the detector is moved too quickly across the surface, the electronics in the instrument will not have time to respond to indicate the amount of radioactive contamination present.

The general method for personnel scanning for alpha contamination is to scan at approximately 2 inches/ sec at a distance of approximately ¼ inch. For personnel scanning for beta contamination, it is recommended to scan at 2 inches/ sec at a distance of ½ inch. However, the surface being surveyed (i.e., soil, building surfaces, equipment, personnel), the scanning speed, and the instrument response time will determine the level of contamination that can be detected.

Failing to survey properly can have the same results as not surveying at all. Contamination may go undetected and may be tracked out of the radiological area. Once outside the radiological area, the contamination may be transferred from surface to surface. This transfer of contamination could result in uranium ending up inside your body, the body of a co-worker, or even the bodies of your family members and friends. The potential for spreading undetected contamination should always be kept in mind when performing self-monitoring.

iv. Interference from Radon

One of the problems encountered when monitoring for contamination is interference from radon and its decay products.

Radon is a radioactive gas that occurs naturally in the environment. It decays by alpha emission in the first of a series of very short half-life radionuclides that decay by alpha or beta-gamma emission.

There is a simple, inexpensive alternative to determine if the contamination is due to radon. The effective half-life for radon radioactive decay products is about 30 minutes, compared with the millions of years it takes for uranium to decay. The simple way to determine if contamination is due to radon is to wait and see if it goes away. The sample is recounted after the radon has an opportunity to decay to lower levels. The count rates are compared, and if the count rates are significantly different, radon is the most likely reason for the higher initial count rate.

h. Special Radiological Surveys and Techniques for Release of Materials with the Potential for Uranium Contamination

The alpha contamination detection problems mentioned in monitoring personnel for contamination also apply to monitoring material. An added problem is that uranium contamination may be located in areas not accessible to survey.

DOE requires that materials used in Contamination Areas, High Contamination Areas, and Airborne Radioactivity Areas that are being released for unrestricted use have accessible surfaces surveyed. Materials with inaccessible surfaces having a potential for internal contamination shall not be released without evaluating the material on a case-by-case basis to ensure internal contamination does not exist.

DOE values for release of uranium- contaminated materials are higher than DOE values for release of materials contaminated with some other radioactive nuclides found in the DOE system, such as plutonium. The difference in these values is due to the relative health risk from exposure to uranium contamination compared with these other nuclides.

Release of materials with the potential for uranium contamination shall only be performed by personnel who are trained and authorized to do so. The site radiological control organization is responsible for designating and training these individuals.

i. Bioassay Monitoring

Bioassay monitoring, or measuring the amount of radioactivity inside the body, can also be a way of determining if there has been a loss of control of uranium contamination. For example, if a person who works in an area with a relatively low airborne radioactivity concentration and shows an intake consistent with a higher airborne radioactivity concentration, there may have been a previously undetected loss of airborne contamination control. Routine bioassay monitoring will assist in making these determinations.

V. MODULE 105 - Criticality Safety

A. Objectives

EO8 Describe the criticality safety control measures for uranium, including inventory control measures.

EO9 Identify criticality monitoring techniques used with uranium.

B. Explanation of Criticality

Uranium is a fissionable material, which means that it can undergo nuclear fission. Nuclear fission is a process in which a very heavy unstable atom primarily splits in two, or "fissions". When an atom fissions, one large atom primarily becomes two smaller atoms, between one and seven neutrons are given off, and a great deal of energy in radiation and other forms, such as the kinetic energy of the fission fragments, is released.

Some unstable atoms, such as ^{235}U, undergo a small amount of fission without any outside influences. This small amount of spontaneous fission does not present a significant hazard on its own, but the neutrons from this fission may be absorbed by other fissionable atoms. When an atom of fissionable material absorbs a neutron, the already unstable atom gains additional energy and becomes even more unstable. One way the unstable atom can get rid of its excess energy is through fission.

When neutrons from one fission cause fission in another atom, it is called a chain reaction. If the chain reaction is self-sustaining, we call this criticality. Criticality is a self-sustaining nuclear chain reaction. This is an obvious radiation hazard because of the amount of energy given off as gamma radiation and other forms.

C. Factors Affecting Criticality

Criticality depends on several factors, including the enrichment of the material, the shape of the material, and surrounding materials, that may help or hinder fission. Several factors which affect the occurrence and magnitude of a criticality:

1. Quantity of Fissile Material

When dealing with criticality, a common question is "How much material can I work with and still be safe?" There is some amount of the fissile material needed to have a criticality. This amount is called the "critical mass."

2. Geometry

To avoid a criticality event, the fissile material must not be placed in a shape, or geometry, that is favorable to criticality. In general, the lower the surface-to-volume ratio is, the greater the opportunity for criticality.

3. Reflectors

Sometimes, neutrons that are emitted from the fissile material may run into or otherwise interact with an atom outside the fissile material and be "bounced back" or "reflected" into the fissile material. Materials such as water, graphite (a form of carbon), and beryllium are good at reflecting neutrons. If the uranium material is surrounded by these reflector materials, criticality is easier to obtain. Accordingly, it is undesirable to store fissile material where there is potential for these materials to be present.

4. Moderators

Another factor that affects criticality is the speed of the neutrons from fission. Neutrons that are traveling at about the same speed as the atoms in surrounding materials are more easily absorbed by fissile materials. Materials that slow the neutrons are known as moderators. Examples of good moderators include water and graphite.

For an example of moderation, consider ^{235}U. This uranium isotope absorbs slow neutrons (also called "thermal" neutrons; these neutrons travel at the same speed as their surroundings) with a rather high probability for absorption. However, ^{238}U only absorbs fast neutrons (those neutrons with high energies that travel faster than their surroundings). Normally fast neutrons are quickly moderated to lower energies, so that ^{238}U will not go critical under normal conditions. The fast neutrons must be moderated, or slowed, to allow ^{235}U to go critical.

5. Neutron Absorbers (Poisons)

If neutron absorbers are present (i.e., atoms and molecules with relatively high neutron absorption coefficients), these materials will remove neutrons from being available to begin or sustain criticality. Boron is an example of a frequently used neutron absorber, or "poison".

6. Concentration or Density of Fissile Material

As the concentration or density of fissile material increases, the opportunity for criticality increases because of an increased likelihood of neutron interaction with the fissile material.

7. Enrichment

Enrichment is the separation of isotopes. With uranium, enrichment is typically referred to as increasing the percentage (by weight) of the ^{235}U isotope in material to greater than that found in natural uranium.

Obviously, the enrichment of uranium plays an important role in criticality because the amount of fissile material available for criticality is greater. For example, the higher the enrichment of ^{235}U (i.e., the concentration of ^{235}U in relation to other uranium isotopes), the greater the opportunity for criticality.

8. Volume

The volume of material in which fissile material is in solution can also play an important role in preventing criticality. For a given concentration or density of fissile material, the amount of fissile material will increase as the volume increases.

9. Interaction

Neutron interaction in an array of containers of fissile material is dependent upon geometric factors, including: size, shape, and separation of the containers, as well as the size and shape of the array. Materials that may surround or be intermingled with the containers are also important. A close-packed array may be come critical if flooded with water which will thermalize neutrons. Also, a less closely-packed array may become critical if the water is removed, allowing less neutron absorption to take place.

D. Safety Policies and Controls

Achieving criticality involves bringing together many factors that promote a sustained nuclear chain reaction. To avoid criticality, one should be aware of the conditions that would promote a criticality for the particular materials they encounter, and avoid those conditions that promote criticality.

1. General Criticality Safety Principles

Some things done to promote criticality safety include:

- analyzing work environments to assess the risk of criticality and eliminate likely criticality concerns;
- using carefully planned and approved procedures;

- providing specific training for those personnel working in areas where fissile materials are present; and
- implementing system design features that are favorable to criticality safety. These features include:
  - using containers with a size and geometry that will not allow criticality,
  - designing piping systems to prevent buildup of uranium and prevent criticality,
  - using materials known as poisons to absorb neutrons and prevent them from being absorbed by the uranium atoms,
  - controlling material that surrounds containers or systems containing uranium, and
  - controlling uranium inventories.

2. Controlling Uranium Inventories

One method to prevent a criticality is controlling uranium inventories. Inventory control involves knowing where the uranium is at the facility and the level of enrichment of the uranium. Uranium enriched in ^{235}U or the presence of ^{233}U is of concern for criticality; therefore, these are materials of concern for inventory control. Criticality is a concern for ^{238}U if fast neutrons are present.

Loss of control of fissile material presents a threat to criticality safety at the facility and, in a worst case scenario, to national security. It is no secret that groups throughout the world are striving to become nuclear powers. Even the appearance of a loss of inventory control must be avoided to keep the public trust and assure continued operations of DOE programs. For these reasons, inventories of fissile material are closely monitored.

3. Facility-Specific Criticality Safety Controls

Provide facility-specific information.

E. Criticality Monitoring Techniques

Provide facility-specific information.

VI. MODULE 106 - Emergency Response for Uranium Incidents

A. Objective

EO10 Understand the facility-specific emergency response procedures involving uranium incidents.

B. Facility-Specific Emergency Response Information

As discussed previously, uranium and chemical compounds containing uranium may represent radiological, fire, chemical, and criticality concerns. Prompt, appropriate emergency response in unusual situations involving uranium is vital to worker and public safety.

VII. MODULE 107 - Course Summary

This training course provides a basic understanding of the characteristics of uranium and the general precautions and controls needed for working in a uranium facility. After this course, participants should be aware of the following basic concepts:

- physical properties of uranium
- radioactive properties of uranium
- chemical properties of uranium
- toxicological propertes and biological effects of uranium on the body
- sources of uranium
- uranium operations and processes
- external dose measurements
- external dose reduction and control techniques
- internal dose measurements
- internal dose reduction and control techniques
- factors affecting criticality
- criticality safety policies and controls
- emergency response for uranium incidents at your facility

The modules included in this training provide a base of general knowledge to better understand facility-specific procedures and training.

(Part 4 of 4)

Radiological Safety Training for Uranium Facilities

Transparencies

Coordinated and Conducted
for
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Radiological Safety Training for Uranium Facilities

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Course Content

- Properties of Uranium
- The Nuclear Fuel Cycle
- External Dose Control
- Internal Dose Control
- Criticality Safety
- Emergency Response for Uranium Incidents
- Course Summary

Module 101

Properties of Uranium

Physical Properties of Uranium

◆ Solid	Shiny, silvery metal
◆ Liquid	Molten metal, solutions
◆ Airborne particles	Radioactive residue
◆ Gas	UF_6

Uranium

- Atomic number Z = 92
- Radioactive
- Alpha emission
- Fission
- Fission products

Radioactive Decay Products

- Most are radioactive
- Generally contribute most of the radioactivity
- Can become concentrated during certain processes

Radioactive Properties

- Radioactive decay products
- Criticality

Flammability

- Uranium burns in air
- Large amounts of water will extinguish a fire, but
- Uranium plus water produces hydrogen gas
- Special fire extinguishers smother the fire

Toxicity

- Heavy metals are toxic
- Uranium is comparable to lead in toxicity

Chemical Reactivity

- Uranium is reactive
- Many possible chemical hazards
- Uranium metal oxidizes in hours
- Uranium chips ignite immediately
- Uranium in water produces flammable hydrogen gas
- Uranium should be in oil for long-term storage
- Concentration of decay products can cause increased exposure rates

Colors

- Lower oxides (e.g., UO_2) are usually
  - dark colored
  - less soluble
- Higher oxides (e.g., UO_3, UO_4, $UO_4 \cdot 2H_2O$) are usually
  - orange or yellow colored
  - more soluble

Module 102

The Nuclear Fuel Cycle

Importance of Uranium

- Historical: orange-colored glaze
- Discovery of radioactivity with uranium, Becquerel, 1896
- Discovery of radioactive decay products, Marie Curie
- Decay products: radium, radon
- Discovery of nuclear fission, 1938
- Plutonium production from uranium, 1940
- First nuclear reactor, Fermi, 1942
- Atomic (nuclear) bomb, 1945

Radiological Safety Training for Uranium Facilities OT-13

Naturally Occurring Uranium

- 0.2% (2 ppt) in uranium ore
- 2 ppm in the earth's crust
- 2 ppb in the oceans

Radiological Safety Training for Uranium Facilities OT-14

Sources of Uranium

- United States
  - Colorado Plateau
  - Wyoming Basin
  - Black Hills
- Africa

Radiological Safety Training for Uranium Facilities OT-15

Nuclear Fuel Cycle

- Mining and milling
- Conversion to other chemical forms
- Enrichment
- Fabrication of fuel rods
- Use in reactors
- Decontamination & decommissioning
- Waste disposal/storage

Radiological Safety Training for Uranium Facilities OT-16

Mining and Milling

- Uranium ore
- Yellowcake
- Uranium mill tailings

Radiological Safety Training for Uranium Facilities OT-17

Conversion

- Uranium dioxide UO_2
- Orange oxide UO_3
- Uranium fluoride gas UF_6

Radiological Safety Training for Uranium Facilities OT-18

Enrichment

- Natural uranium 0.7% ^{235}U
- Enriched uranium > 1% ^{235}U
- Highly enriched uranium $\geq$ 20% ^{235}U
- Depleted uranium 0.2% ^{235}U

Radiological Safety Training for Uranium Facilities OT-19

Uses for Enriched Uranium

- Commercial power reactors
- Naval propulsion power reactors
- Research reactors
- Nuclear weapons

Radiological Safety Training for Uranium Facilities OT-20

Uses of Depleted Uranium

- Shielding
- Armor-piercing bullets
- Catalysts
- Armor plating
- Counter weights

Radiological Safety Training for Uranium Facilities OT-21

Fuel Reprocessing

- Expose fuel material
- Remove fuel from cladding
- Chemically separate the uranium
- Convert uranium to UF_6 for enrichment

Radiological Safety Training for Uranium Facilities OT-22

Waste Disposal and Storage

- Low-Level Waste (LLW)
- High-Level Waste (HLW)

Radiological Safety Training for Uranium Facilities OT-23

D&D of Uranium Facilities

- UMTRA
- FUSRAP
- SFMP
- Commercial facilities

Radiological Safety Training for Uranium Facilities OT-24

Module 103

External Dose Control

Beta Radiation

- From the decay products
- Mostly external
- Shallow dose
- 30 rad/hr $(^{234m}\text{Pa}\ \$)$

Gamma Radiation

- Usually less than 5 mrem/hr (0.05 mSv/hr)
- Decay products can become concentrated
- Fission products
- Criticality (potentially fatal doses of gamma radiation)

Neutron Radiation

◆ Enriched UF_6	4 mrem/hr (0.04 mSv/hr)
◆ Spontaneous fission	small
◆ Fission from reactors or experiments	contained
◆ Criticality accident	potentially fatal

ALARA - External Dose

To keep external exposure ALARA:

- Minimize time
- Maximize distance
- Use shielding
- Reduce the amount of radioactive material being used

Beta Radiation Protection

- Easily detected
- Easily shielded
- Use low-Z elements to minimize bremsstrahlung
  - heavy rubber or plastic over objects
  - safety glasses for the lens of the eye
  - heavy work gloves for the hands

Module 104

Internal Dose Control

Internal Exposure

Modes of entry into the body:

- Inhalation
- Ingestion
- Absorption
- Injection

Contamination Control - 1

Proper contamination control will

- Limit internal dose by minimizing ingestion or inhalation
- Limit external dose by reducing the source
- Prevent the spread of radioactive materials into uncontrolled areas

Contamination Control - 2

Contamination can be controlled by

- Evaluation of work activities
- Use of containment devices
- Control and monitoring of airborne contamination
- Minimization of contamination areas
- Control of movement of equipment and personnel
- Protective equipment
- Special radiological surveys and techniques for contamination monitoring
- Special radiological surveys and techniques for release of materials with the potential for uranium contamination

Airborne Contamination

- Cutting, grinding, welding, etc.
- Ventilation and filters
- Air sampling and monitoring
- Respirators should be considered (as a last resort)

Protective Clothing

- Coveralls
- Booties or dedicated work shoes
- Gloves, unless there are overriding reasons

Module 105

Criticality Safety

Criticality

- Fission breaks atom into fission products
- Fissionable: with fast neutrons
- Fissile: with slow or fast neutrons
- Self-sustaining chain reaction

(Facility-Specific)

Module 106

Emergency Response for
Uranium Incidents

Module 107

Course Summary

Course Summary

- Physical properties
- Radioactive properties
- Chemical properties
- Toxicological properties and biological effects
- Sources
- Operations and processes
- External dose measurements
- External dose reduction and control
- Internal dose measurements
- Internal dose reduction and control
- Factors affecting criticality
- Criticality safety
- Emergency response

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CONCLUDING MATERIAL

Review Activity:			**Preparing Activity:**
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DP	AL	RFFO	
EH	CH	OH	**Project Number:**
EM	ID	GFO	6910-0056
NE	NV		
NN	OR		
ER	RL		
	OAK		
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